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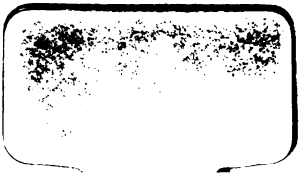
THE AIR
IN RELATION
TO
CLOTHING, DWELLING
AND SOIL.



THE

RELATIONS OF THE AIR

TO THE

Clothes we Wear, the House we Live in,

AND

The Soil we Dwell on.

THREE POPULAR LECTURES

DELIVERED BEFORE THE ALBERT SOCIETY AT DRESDEN.

BY

DR. MAX VON PETTENKOFER,

Professor of Hygiene at the University of Munich, etc.

ABRIDGED AND TRANSLATED BY

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NOTICE.

HAVING been requested frequently and in many quarters, to publish these Lectures upon some subjects of Public Hygiene, the Author hereby complies with the request. In this way, the contents of these Lectures become accessible to a larger circle of intelligent persons. With the rising interest in the questions of Hygiene, it becomes the duty of the Press to contribute towards the proper direction of the existing spirit and attention of the public to important general facts and views, which are the objects of scientific work. There has always been a desire to ameliorate the public health, and guard it against disease; but at different times very different means have been in use or contemplated for this end. Even now, there are neither definite notions existing, nor are those existing correct, even about the every-day and most important influences of the things which surround us, and on which our health depends. These Lectures will bring home to the mind of all educated and intelligent readers how much is to be done, to be created, and to be changed in this direction, and how much good will then and certainly be effected. The end of the third Lecture will principally open a view over the extensive field which is waiting for cultivation, as well from an exact scientific as from a practical stand-point.

THE AUTHOR.

PREFACE OF TRANSLATOR.

THE ALBERT SOCIETY at Dresden is a Ladies' Association, which aims chiefly at the training of efficient female sick-nurses, and at other charitable purposes. It was at the particular request of H.R.H. THE CROWN-PRINCESS CAROLA OF SAXONY, who is the President of the Society, that Professor Pettenkofer gave these Lectures.

I was struck with their high tone, and with the ability with which an apparently simple subject was rendered interesting and instructive in the highest degree.

Considering the prominent position which Hygiene occupies now, the contents of these Lectures, although referring only to one small branch of the large subject, cannot fail to be of deep interest to many persons, and, if well digested, to produce a desire for more knowledge of the same kind.

In reference to the temperature of the human body, often mentioned in these Lectures, I cannot refrain from stating here my opinion that a good *medical thermometer* would be a more useful implement for many families than the medicine-chest, whose contents, in towns at least, are generally procurable at any time. Its application can often decide whether a medical man is to be sent for or

not. During a case of severe illness, its application and the report thereupon by a person instructed how to use it, will be of great importance for a successful treatment. This hint must suffice in this place. The matter rests with the medical advisers of the Public.

The weights and measures, etc., etc., have been changed from the Continental into English ones.

A. H.

LONDON, *June*, 1873.

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FIRST LECTURE.

THE RELATIONS OF THE AIR TO THE CLOTHES WE WEAR.

The Committee of the Albert Society has honoured me by an invitation to give a few popular Lectures at *Dresden*, on subjects of Public Hygiene. Let me state to you at once what I think of popular Lectures in general.

What ought they to be, and what can we expect from them? I am not one of those who, in all their work and aim, look out directly for the practical use, for the return on the capital, immediate or prospective; but on the other hand I feel myself bound, in a certain degree, to inquire into the object of much that may appear to be either unprofitable or useless.

There is no doubt that *popular* Lectures on *scientific* subjects will not impart really competent knowledge, and will not form experts. Therefore it will be maintained by many that such Lectures produce more evil than good, creating as they do, and augmenting, that dilettantism from which our period is already suffering. In our schools also this dilettantism is gaining such dimensions, that one might get thoroughly frightened at the immoderate expansion of young people's knowledge, were it not for its small depth, which lessens the danger, and for the fact

that the forgetting keeps apace with the learning. Accept my open avowal, that I also am unable to invalidate the objection, that *popular* Lectures on *scientific* subjects are not able to impart a really competent knowledge, and do not form experts.

But I believe that this does not matter, and that they have no such purpose. They are neither an exhaustive, scientific, nor a practical instruction, but a scientific edification and elevation, which are to raise our minds and hearts, and to affect us like listening to good music—to a symphony, the purpose of which is certainly not to make musicians of all the listeners. It is sufficient to feel the harmony which lies in the nature of good music. There is harmony in all our knowing and doing, our aiming and striving, as far as there is *truth* in them, and fortunately the sense for perceiving this harmony is as widely spread among mankind as the sense for music. This harmony, which pervades every truth, ought to be brought home to the consciousness and feelings of everybody, so that the greatest number may rejoice and become interested in it, that we may approach new subjects, and perhaps make them our study, or that at all events, knowledge and resulting sympathy may induce us to lend our help to those men, whose profession and calling requires them to enter more minutely and exactly into the subjects in question. In this respect, popular Lectures have a high and serious mission. It is their mission to create correct general ideas, to facilitate our grasp of them, to awaken and spread a certain love for different tasks of mankind and of the period, to form ties of friendship between things, ideas, and men. Sympathy and sacrifices cannot be expected or asked from us, if their objects are unknown to or badly understood by us.

For these reasons it is my desire to awaken your interest for some subjects relating to Hygiene, and particularly to impress upon you most vividly, how much in this respect remains to be done and created, a work we all ought to take our share in.

One of the incessant wants of man is air.

We want air mainly to nourish us and to keep us cool. The quantity of air inhaled and exhaled by an adult in 24 hours amounts on an average to about 360 cubic feet, or 2000 gallons. What we take in and give out during 24 hours in the shape of solid and liquid food, occupies on an average the space of $5\frac{1}{2}$ pints, which is equal to $\frac{1}{3000}$ of the volume of the air passing through our lungs. It will astonish you to hear perhaps for the first time, that this amounts to 730,000 gallons in one year, and to be reminded of that continuous work, which goes on day and night—a never ceasing bellows-blowing, by which the organ of our life is kept in play. Of course the quantity of air flowing round the surface of the human body is much greater than that. Do not object, that air is something so light that it need not be taken into account. It has some weight; water certainly is 770 times heavier, but our daily 2000 gallons have for all that a weight of 25 pounds avoirdupois. Still as it is not my intention to dwell here upon the subject of our oxygen-alimentation, I will to-day consider only the second use we make of the air, the cooling of our working machine.

You all know that life is bound up with chemical processes, kept in continual activity through the ingestion of solid and liquid food, and of oxygen from the air. One of the conditions for the normal performance of these processes is a definite temperature, above and below which they (although not brought to a standstill) go on

differently—they leave off performing the functions of normal life—they lead to disease or death. With man this uniform temperature of his organs is one of the most essential conditions of life. The blood of the Negro living in the torrid zone of the Equator is not by $\frac{1}{5}$th degree warmer than that of the Esquimaux in the highest north at the coldest time of the year—it is always $99\frac{1}{2}^0$ F. The extremes of temperature under which human life exists, are 95° to 104° F. in the tropics, and 57° to 84° under freezing point in the polar regions. There are even differences of 72 degrees in the mean monthly temperatures of some countries, and yet the organs of man are everywhere of the same temperature.

By what means is man enabled to meet such colossal differences? What are his weapons for sustaining this gigantic struggle?

Let us look a little nearer into the absolute quantities of heat the living organism has to manage. The chemical processes going on in an adult person within the space of 24 hours, produce about 12,000 caloric units. By caloric unit Natural Philosophy designates that quantity of heat which is necessary to raise the temperature of one pound avoirdupois of water by one degree of Fahrenheit.* By the heat produced by one person during one day about 660 gallons of water could be made warmer by nearly two degrees, or $7\frac{1}{3}$ gallons could be heated from freezing to boiling point, from 32° to 212° F.

Under certain conditions man produces more or less heat; for instance, according to the quantity of food he takes, or the degree of muscular exertion he undergoes, such deviations from the mean amounting at times to 50 per cent. of the whole quantity; but it is always the task of

* Rankine's caloric units are used by Translator.

the body, and a strict condition for the maintenance of health, to keep the heat of the blood substantially the same, or at least within two degrees.

We have to look upon ourselves as warm and humid bodies placed within a cooler atmosphere. Such bodies lose their heat in three different ways: 1. Radiation. 2. Evaporation. 3. Conduction. This triple arrangement is of great advantage for the heat-department of our organism, in as much as the existence of these different routes allows of a delicate regulation—that, for instance, which we lose in a given case by radiation can be made up by diminution of loss through the other routes, and *vice versa*. The losses by radiation and by conduction are the most constant under equal conditions, and evaporation of water is the principal means for equalising differences resulting from varying production of heat or from difficulties of the two other routes. Allow me to illustrate this by drawing your attention to some every day phenomena.

You arrive for instance in an hotel after a journey during a cold winter's day, and have at once a fire lit in your room. Let the fire be ever so bright, the thermometer even rise to a reassuring degree—you must stick to the fireplace, the room does not get warm. If you continue to live in the same room and have the fire kept in, it will by-and-bye get comfortable even if the thermometer in the room should stand lower than on the first day, and you will think quite correctly that the room wanted time to get warmed through and through. Before that had taken place, the loss of heat by increased radiation into the incompletely warmed space made itself sensibly felt in the heating department of your body. Radiation is the stronger the greater the difference of temperature between two bodies. Surrounded as you are

in a room not only by air, say of 68° F., but also by walls, furniture, &c., which stand perhaps at 38° to 40°, your body radiates its heat particularly towards these colder objects, till they also get warmer. For a room to be warm, it must get warmed with all which it contains.

Let us now look at the contrary case, when our loss by radiation is uncommonly limited; for instance, in a thronged room on a warm and moist day. You feel an oppressive heat, and scarcely trust the thermometer, which marks only 68 degrees, perhaps your favourite temperature. Quite correctly, you accuse the throng of people, and retire into an adjoining room, where you find the air delicious, and seem to receive new life; there, again, the thermometer is suspected by you, as it is scarcely different from its colleague inside; and if the air in the two rooms were to be examined eudiometrically, the difference would be so small as to leave unexplained the difference in your sensations. What, then, causes this difference? It is the suppression of your lateral radiation of heat, when you are in the midst of other equally warm bodies; your receipts and expenditure by radiation cover each other, and the cooling of the individual limits itself to the two other routes, conduction by the air moving round him, and evaporation of water from his surface. On such occasions the pores of your skin pour forth a quantity of water, and, at the same time you instinctively try to increase the movement of the air, that means, its quantity in proportion to your surface; you want to increase your loss by conduction, and, if possible, by evaporation, and take to fanning, in order to facilitate the departure of your rising heat by the two open routes.

The loss by radiation can be very considerable under

certain circumstances; 50 per cent. of the whole quantity of heat generally going that way, it is obvious that radiation deserves our full consideration. Particularly, an unequal radiation may be very injurious, such as takes place when a person is sitting or lying near a cold wall which is not covered by some bad heat-conductor, or near a window, &c.

On school-forms, the exposed sides of the first and last pupils are always more cooled than the sides directed towards their neighbours. In this respect, there are numbers of practical points, which are far from being sufficiently taken into consideration.

Let us now consider some instances in which the abstraction of heat by evaporation is predominant, or preeminently felt. The best known is that experiment, by which one tries to learn the direction of the wind when the air appears calm and the sky cloudless. The moistened forefinger feels colder on that side which looks towards the wind, because more evaporation takes place there. The experiment does not succeed so well when the air is moist, because the moisture in the air prevents further reception of moisture by it; in our case, preventing the evaporation from the moistened finger.

Our organism acts similarly in all cases where there is an increased production of heat in our body, or where less heat is sent away by the two other routes. It has the power of dilating or narrowing the small blood-vessels in our skin and internal organs. The blood-vessel-nerves which govern this motion are not subject to our will, but liable to be excited by external causes. When a person blushes, he gives off heat, because more blood rushes into the dilated blood-vessels of his cheeks and periphery generally, and more heat leaves the body.

Under similar circumstances the whole surface of our body becomes fuller of blood and warmer, there is more heat to radiate and to be conducted away, and to be consumed by increased evaporation of the watery part of the blood.

The great value of evaporation for the cooling of our body can be estimated by calculating that, as little as fifteen drops of water requires 2¼ caloric units to be changed into vapour.

We have at Munich a great apparatus for studying the process of respiration. It was given by the late King of Bavaria, Maximilian II., to the hygienic department of the university. Professor Voit and myself have, by aid of this apparatus, investigated the quantity of water evaporated by men and animals during twenty-four hours. The constant result was that, under other similar circumstances, the quantity of evaporated water, always rose in proportion to an increased metamorphosis of tissue, whether this increase was the consequence of increased nutrition, or of muscular exertion. We have experimented upon men at rest and at work, and we have found, that on a day of rest they usually evaporated through lungs and skin about two pounds only during twenty-four hours, and on a day of hard work four and a-quarter pounds of water. In the first instance, about 2,016 caloric units, in the second, 4,480 had to leave the body, in consequence of evaporation.

This explains to you, how it can be, that even with the hardest work our blood will not become warmer, but sometimes even cooler. The last observation has been made quite recently in mountaineering expeditions. Professor Lortet, of Lyons, found, when he made an ascent of Mont *Blanc, that* the temperature in his mouth and armpit was

less than normal, and became normal only when he was at rest. On such high mountains the lessened pressure of the atmosphere favours the peripheric circulation, there is a rush of water to the surface, and its evaporation takes place more readily, and increases with the altitude. At great heights persons in a balloon constantly complain of great dryness in the mouth.

Professors Voit, Recknagel, and myself, are just now occupied in investigating the economy of animal heat, and we have found, that after six hours' hard work the person leaves the apparatus in a cooler condition than when he went in, or after he had been at rest in the apparatus for the same space of time. Of course the ventilation of the apparatus must work well, and send per hour about 11,100 gallons or 1,800 cubic feet of air through the chamber, else less water and less heat depart by evaporation.

You see what powerful means of cooling our body we have in the increase of our peripheric circulation, and consequent evaporation, at a time when the other routes are not open sufficiently—but you see also how dangerous this means can become, if it is employed at a time when considerable quantities of heat depart on the other routes. If, heated and damp, you enter suddenly a cold space, where radiation increases at once, and a good deal of heat is also yielded by conduction to the cold air, you are in great danger of contracting an illness by the abnormal losses of heat, and the violent and sudden changes in the circulation. But if you undergo such changes slowly and gently, the three routes open themselves harmoniously. Our organism is a faithful and clever servant, who helps himself and his master, provided he is not hurried and ill-treated. When I come to speak

of ventilation, I shall not forget to speak to you of currents of air, called Draughts.

The third route, that of conduction, by which we give up heat to the air, is also of great importance, and must in some circumstances replace the two others to a considerable degree. As long as our body is warmer than the surrounding air, this air gets warmer at every point of contact with our body, but at the same time lighter, and as such it is displaced by colder and heavier air, which in its turn gets warmer and lighter, and so on.

Each person standing in the still air of a room, causes in this way an ascending current of air, just like a heated stove. A very sensitive Anemometer, placed between coat and waistcoat, shows the existence of this current, which is strong enough to set the little wings of the instrument in play. The air in this room appears quite still, and yet it is in thousand-fold motion and ceaseless restlessness; but happily our nerves are not aware of this, just as a shortsighted person may deny the existence of some object, till his eyes get the assistance of a glass. Whoever of you would be able to feel or see all the movements of the air in this room, would probably not be able to stand it. A correct idea may be formed about it by the action of smelling substances. If, for instance, an escape of gas were to take place in a remote corner of this large room, you would become aware of it almost immediately all over the room. Our nerves are happily so organised, that they begin to feel the motion of the air only when it amounts to about 3¼ feet per second.

You may have some doubt about this ignorance of your nerves, because the proof lies not in our immediate perception, but in conclusions from other observations; but you may easily convince yourself that it is so. It is the

same thing whether you move your hand at a certain rate through a still air, or whether air moves at the same rate round your hand. You will find that you do not feel anything, no resistance, no coolness, if you move your hand at less than 19 inches per second.

I take this opportunity to draw your attention at once to the average movement of air out of doors, a subject very imperfectly known to most people, but which you must understand well, in order to have a correct idea of the real difference between being in a room or in the open air. The velocity of the air is measured by an instrument called Anemometer, a description of which you can easily get at. In our temperate climate this velocity amounts on an average to about 10 feet per second. This would make about 7 miles per hour. Imagine a frame about the height and width of a human body, let us say it measures about 6 feet by $1\frac{1}{2}$, or 9 square feet. If you multiply this by the average velocity of the air, you will find that in one second 90 cubic feet, in one minute 5,400 cubic feet, in one hour 324,000 cubic feet of air flow over one person in the open. I shall come back again to these numbers when we have to consider the subject of the ventilation of dwellings, but you will already understand that it is not too much if 2,100 cubic feet of new air per hour and per bed, are considered necessary in the ventilating arrangements of hospitals, etc. This quantity, which appears large, is after all only about $\frac{1}{16}$ of the quantity of air which comes in contact with a person in the open at the above stated average velocity of the air.

You see, therefore, that we give off more heat by conduction in the open air than in a room, and in the latter, proportionately more by radiation and evaporation.

The power of conduction is best appreciated when we change the air for some other fluid medium, which is a better conductor than air, and more capable of absorbing heat, I mean water. In air of a few degrees of heat, we can feel pretty comfortable with moderately warm clothes; but if with the same amount of clothing we were to get into water of the same temperature, we should feel painfully cold, and should probably be frozen to death in a few hours, although our loss by evaporation would have ceased entirely, and that by radiation nearly so. In hot climates, therefore, a daily bath is of great service for the necessary cooling of our body, even if the water is not cooler than the atmosphere.

In the air also the loss of heat by conduction is the greater the lower the temperature and the greater the velocity of the air which flows around us. This explains on the one side, why it appears superfluous in a calm and cool air to make use of a fan, while this expedient acts so beneficially at higher temperatures; and on the other, why, as a rule, a warm air in motion appears much cooler than a calm one of equal temperature.

Think of the sultriness before a thunderstorm, as long as the air is at rest, and how differently we feel as soon as the first wind rises. The air is not yet cooler, not less saturated with vapour than before, and still it deprives us of so much more heat, that we deem it less sultry, even cool, only because it travels over us faster.

When we fan ourselves in a hot and damp air, the same takes place: then also a greater amount of air passes over us in a given time than if we leave the air to its own motions. The fan changes nothing in the temperature and moistness of the air, it only increases its velocity, and in consequence the abstraction of heat, and thus affords us

coolness chiefly on the uncovered or only slightly covered parts of our body; therefore ladies have more reason for using it than the stronger sex.

As long as the air is our surrounding medium, an increased evaporation associates itself with the increased loss by conduction, at least as long as the circulation of the blood in the skin remains active and the air is not saturated with moisture. The fan scarcely ever cools by increased conduction alone, but also by increased evaporation. Therefore, fanning with dry air is much more cooling than fanning with a moist air of equal temperature. We all know how much quicker wet roads and wet clothes dry when there is a good wind. However rapid the motion of moist air may be it does not dry. When our body is bathed in perspiration the fuller condition of the skin occasions an increased transfer of heat from the dilated blood-vessels to the surrounding air by conduction, but generally also by evaporation.

In southern climes, at the hottest and moist time of the year, when the body cannot lose much heat by radiation towards colder objects, when the temperature of the air approaches and even surpasses at times that of our blood, the European often feels the heat to suffocation, and besides the use of the bath he has no other practical remedy than the fan and the shade.

In the shade the air is not only cooler, but also more in motion. The difference of temperature between a place sheltered from the rays of the sun and a neighbouring one exposed to them, produces a motion, a current, because bodies of air of unequal temperature are also of unequal weight. They are not in equilibrium, and seek to re-establish it by motion. Any one may easily convince himself thereof who, on a hot day with

calm air, walks alternately over places exposed to the sun and sheltered from it. As soon as he comes into the shade of a cloud, a house, or a tree, he feels at once a soft wind rising. The shade not only protects us against the direct solar rays, but it increases also the ventilation of the shady place.

The fan acts on the same principle. The Pankah in the bungalow, by increased conduction and evaporation, keeps the blood of the European at its normal temperature of 99½°. When the temperature of the air rises to 140°, when the walls of the house or bungalow are no longer cool enough to provoke radiation from the heated human body, man is reduced to cooling by evaporation. It greatly depends upon the state of dryness of the air how far he succeeds. The drier the hot air is, the better is it able to withdraw water from the skin, from the respiratory organs, from the wetted floors, and consequently the more heat from the human body. The moister it is the less it is able to act thus.

In order to give you an idea of the quantitative differences in play, we will consider the losses of heat by respiration as they take place at different temperatures and different conditions of moisture of the air we draw in. In twenty-four hours the quantity of this air is on an average 2,000 gallons. It has been calculated that by the process of respiration a person loses 1,172 caloric units when the air is at 32° and quite dry, 1,116 when it is half saturated by water, 1,060 when it is completely so. The difference between the two extremes is only a small percentage of the whole loss. But when the temperature is 86 the above numbers would be respectively 1,096, 760, and 420.

A comparison of the losses of heat by the respiration of

an absolutely dry and an absolutely saturated air at 32° and 86° F. is highly instructive. We lose:—

at 32° and dry	1172	Cal. units.
„ 86° „ „	1096	
diff. only	76	
at 32° and satur. . . .	1,060	
„ 86° „ „ . .	420	
diff. as much as	640	Cal. units.

The different state of dryness of the air appears thus to be of a greater moment than the difference of temperature, and this is the reason why our sensations do not always coincide with the thermometer. You readily understand how much more difficult it is to manage one's heat-household in a hot than in a cold climate. Our means for warming ourselves are better than those for carrying off our heat. Therefore the European race has a hard fight under the Equator. The working power of the body depends on a certain amount of consumption, by which a certain amount of heat is necessarily created, which has to leave the body in a regular way. The Hindoo who has to draw the European's Pankah, bears the heat better in proportion as he takes less food and creates less heat in himself, but then his working power is also quite proportionate to the total of his consumption.

The European's struggle in a hot climate, and his dangers of degeneracy will remain the same as long as he has no better means of cooling himself by some or all of the known three routes. Houses with thick stone walls are tolerably efficacious. These walls rarely get warmer than the average temperature of the year. They cool the air which comes into the house, and act on the inmates in the way we have seen when speaking of the

room which is not warmed through and through. A good means would be some contrivance by which the air in the house could be deprived of its water.

I could not help inflicting upon you this rather long introduction, nor could I possibly abbreviate it, as without the little knowledge which I have tried to impart to you about the cooling of the human body, you would not be enabled to obtain a proper insight into the functions of our clothing and our dwellings. Therefore I believe myself to have had a good claim on your patience and indulgence.

One of man's principal defensive weapons in his struggle for existence is his clothing. The place it takes in the history of civilisation and its connexion with Physiology are not often thought of. People speak about it generally from a moral and æsthetic point of view, but the main purpose of clothing is seldom approached in conversation —I mean the purely hygienic one. I deem this to be a misfortune, because this forgetting of the chief point has subjected mankind to the rule of small and frivolous considerations, and the manners and fashions of the period get frequently the better of the hygienic fitness of the clothing. Morality and beauty do not depend on dress. They cannot be created or preserved by it. These great qualities could even exist without it, but the human body as it is could not, or only barely and imperfectly, exist in our climate without the protection of clothing, which is more indispensable for our health than for our beauty and morality.

So manifold are the changes brought about in our system by clothing ourselves, that I am unable to give you more than some incomplete parts of the subject.

When I cover one part of my body I change the degree

of abstraction of heat by all three routes known to you, but without obstructing any one of them entirely.

To speak in the first instance of radiation, it will be clear to you that our surface is prevented from radiating heat directly towards the colder objects in our neighbourhood, and that it can only radiate towards the covering materials, which receive this heat. By the laws of conduction and radiation the heat, which has radiated from the body into the clothes, has to travel through them by radiation and conduction, till, arrived at their outer surface, it can radiate from thence towards colder objects, just as it would from the naked surface of the body. Thus by our clothes we keep the heat radiating from us somewhat longer in the immediate neighbourhood of our surface. The lightest covering even makes itself perceptible by impeding radiation, the thinnest veil keeps warm in some degree. It is just the same with the earth itself. On a calm, clear night the earth's surface becomes so chilled by radiation into the colder space, that the moisture of the air precipitates itself on it as dew, and at times as hoar frost, and even as ice, just as the moisture in a warm room does on a window-pane cooled from the outside; but when a veil of clouds overhangs the earth during the night the earth never cools itself so much as to allow of any dew forming.

There are substances, called diathermal, which allow the rays of heat to go straight through them without any absorption, for instance, the crystals of common salt; but all the materials of our clothes are such as absorb the rays of heat which come to them from one side, and only part with them after they have reached the outer surface. The transit of heat through what we may call our artificial surface depends essentially on the conductive power

of the material and its thickness, *i.e.*, on the length of time and way which the heat has to go through in order to travel from our surface to the outer surface of the garment.

Thus the whole immediate neighbourhood of our body is continually warmed in an even degree by our radiating heat, and our sensitive skin is spared the numerous disagreeable or injurious effects of a rapidly changing temperature.

The heat does not remain in our clothes, it is continually on an outward move, faster or slower, and to a certain degree also warms the stratum of air between our clothing and our skin, so rich in nerves and blood-vessels. This air, as we shall see presently, continually changes, and must change if we are to feel comfortable. In the cold of winter and in the open air we lose our bodily heat out of our well-selected garments without any sensation of cold, only because we have removed the place of exchange between the temperature of our warm blood and the cold winter air from our sensitive surface to a substance without life and sensation; instead of our skin our dress feels the cold. It is the same with the hair of animals and the feathers of birds, they are also without nerves.

In proportion as our heat-losses increase, while the creation of heat in our interior remains about the same, we feel the necessity of diminishing the rate at which the heat leaves our immediate neighbourhood. This kind of regulation is somewhat taken care of involuntarily even by the naked body. In consequence of the cold the nerves which act on the calibre of the blood-vessels of our surface contract them, and lessen the quantity of blood in them, so that less heat comes to the surface, and we need not be

afraid of becoming also inwardly colder if we feel cold, even very cold.

The sensation of cold on the skin does not necessarily give the measure of our internal temperature. In the cold stage of ague, for instance, the temperature of the internal organs rises considerably, while by a kind of spasmodic contraction of the superficial blood-vessels the flow of heat towards the skin is less than normal. The above-mentioned regulation of heat-loss by the capillary system of our skin is not all-sufficient either in point of time or degree. The cold may be too strong, and the regulator get overworked and paralysed, so that additional clothing is required to delay the departure of our heat, and to spare the nerves of the blood-vessels. We help ourselves by additional clothing, and the underlying article of clothing stands in the same relation to the outer one as the skin to its first covering. From this point of view you have to consider the sequence of shirt, underclothing, coat, overcoat, &c., &c., an arrangement by which we save the vasomotor nerves the greater part of their work.

It is an open question, which the incompleteness of our hygienic knowledge prevents us from answering quite satisfactorily, how far we ought to hand over the regulation of our heat-loss to our dress, or how far we should go in deputing it to our organism, and its capability of transferring more or less heat from the centres to the surface of our body. This self-help of the organism, and the readiness for it resulting from frequent exercise of this function is generally called hardening oneself; the contrary, making oneself tender. The former we can never quite dispense with, but I believe that too high a value is sometimes put and too large claims made on it.

One ought to possess the capability and the readiness, but not to make use of them continually.

All human aim must be to obtain the greatest effect at the smallest expense. We ought to choose those means which attain the end without exhausting our power, which should be preserved for higher purposes. These principles ought to guide us in approaching the question. It is not only superfluous, but positively injurious to use oneself up.

I believe that it is now evident to you that a part of the heat of our body radiates from the surface of our clothing; but we must now consider whether this radiation does not vary according to the nature, quality, or colour of the material. Experiments which have been made by *Dr. Krieger* * on wool, washleather, silk, cotton, linen, and india-rubber have not shown any important difference. *Krieger* covered cylinders made of tin and filled with warm water with different and differently arranged materials, and noted the decrease of temperature in stated periods. He used layers of two different materials, but it made no great difference what the outer layer was. Still I will mention that silk and cotton allowed more heat to radiate than wool. The colour also of the material has been shown to have no great influence on the radiation of heat, which remains the same whether we have a black or a white garment on.

But it is quite another case when we receive luminous heat, rays of heat proceeding from luminous bodies, such as the sun, or some flame; then differences result, which certainly are not very great with different materials of the same colour, but become great indeed when the colours are different. For white textures the following proportions are found:—

* See Appendix.

When cotton received	100
Linen received	98
Flannel „	102
Silk „	108

With shirtings of different colours the proportions were :—

White	100
Pale Straw-colour	102
Dark Yellow	140
Light Green	155
Dark Green	168
Turkish Red	165
Light Blue	198
Black	208

Of course you all know by experience that dressed in black you feel much hotter in the sun than dressed in white. It is remarkable that, pale straw excepted, each colour heightens considerably the absorption of luminous heat-rays, and that blue does so nearly as much as black. But as soon as we are in the shade the differences nearly vanish.

If we continue to consider our loss of heat by radiation through and from our clothing, (omitting for the present conduction and evaporation), we come at once to the practical question, how much this loss is retarded by interposing several strata of material between our surface and the air, or in fact to the question about the heat-conducting power of materials and textures. Very few experiments have been made in this respect. We know, with respect to this point, the properties of metals, of minerals, of chemical compounds, but not of wool, linen, or leather. This shows by-the-bye, how little Hygiene has been treated until now in an exact and scientific way. We talk in a general way about the use of garments as bad conductors of heat, but the few experiments known to me entirely run *counter to* our accepted ideas.

Kr'eger experimented on cylinders filled with warm water, by surrounding them tightly with single or double textures. As the loss by radiation is the same in both cases, any difference must result from difference of conductive power in the coverings of the cylinders; but the results were, for the most part, surprisingly small. The following numbers represent the proportions of loss of heat through double tight-fitting coverings in comparison to single ones; the losses through the single ones being taken as 100, they were, through:—

Double	thin Silk	97
„	Gutta Percha	96
„	Shirtings	95
„	Fine Linen	95
„	Stout Silk	94
„	Thick home-spun Linen	91
„	Chamois Leather	88—90
„	Flannel	86
„	Summer Buckskin	88
„	Winter ditto	74—84
„	Double Stuffs	69—75

The whole question is certainly not exhausted by these experiments, but one thing becomes evident by them, that it is not the substance and its weight, but the texture and the volume, which are the principal causes of the difference. Thin and stout silks, fine and stout linen are nearly equal in substance, and equal sizes of them are not so very different in weight; it is their different heat-conducting power which causes the difference of the loss, and this is, even through two layers of them, not as much as 10 per cent. smaller than through a single one.

By other experiments one can demonstrate, that by *changing the* shape and volume of the same substance, *great changes of* heat-loss can be produced, although the

substance and its weight remains the same. If you cover the tin cylinder, previously filled with warm water, with common wadding, and observe the falling of the immersed thermometer, you will be astonished to see how rapidly the fall goes on, as soon as you compress the wadding firmly and diminish its volume: the outward flow of the heat increases by 40 per cent. The same, you know, is the case, when a wadded garment is worn out; the quantity of the wadding is the same, but its volume and its elasticity have undergone a change, and you will find it considerably less protecting.

This observation leads to another instructive experiment, relating to the influence of double layers of material. If the first layer only is tightly drawn over the warm cylinder, and a free space of $\frac{1}{3}$ to $\frac{1}{2}$ an inch between it and the second, which may be compared to a comfortably sitting garment, the second layer very considerably lessens the outward flow of the heat. The amount due to conduction being deducted, the impediment by the second layer is about the same for different materials, but very considerable for each of them—

For Linen	32 %
„ Shirting	33 „
„ Silk	32 „
„ Flannel	29 „
„ Wash-leather	30 „
„ Gutta Percha Sheeting . . .	36 „

From this follows the practical truth, that we can produce a very different effect on our body by the same number of clothes, according to the tightness and looseness in the the make. Just call to mind tight shoes and gloves in winter time!

This fact leads to a series of other facts, which contain

the explanation why wadding, as long as it is loose and elastic, keeps you warmer than when it is once flattened. This is the air contained within the clothes.

One generally considers clothing as an apparatus for keeping the air from us. This conception is utterly erroneous; quite the reverse, we can bear no garments which do not allow of a continual ventilation of our surface. Just those textures, which are most permeable to the air, keep us warmest. I have examined different materials for their permeability to air, which can be easily ascertained. One closes a series of perfectly equal glass tubes with different textures, and observes how much air passes through the clothing substances at the same pressure during the same time. Taking the quantity of air passing through flannel as 100,

Linen allowed	. . . . .	58
Silk	„	40
Buckskin	„	58
Kid	„	1
Chamois	„	51 parts of air

to pass through them.

If our clothing kept us warm in proportion to its power of excluding the air from our body, kid would keep us a 100 times, chamois warmer by one half than flannel and so on, while everyone knows by experience, that it is quite the reverse.

If there are several layers of the same material, ventilation loses but very little at the second layer, because the velocity of the air in its passage through the first layer, remains about the same on its further progress, the following layers being like a continuation of the preceding ones, as if they were tubes of the same calibre, retarding the *original* velocity of a fluid by the amount only of unavoid*able friction.*

Thus a current of air travels incessantly through our clothing. Its force, as in ventilation generally, depends on the size of the openings, the difference between the outside and inside temperature, and the velocity of the surrounding air. We need not be anxious to make our clothes prevent the access of air to our skin, they have only to regulate and to moderate it to such a degree that our nerves may not feel the air as something in motion. This degree is far from immobility. When in the open air we believe it to be quite calm, there is still a velocity in it of at least $1\frac{1}{2}$ feet per second, or about one mile per hour, as you heard before.

Our clothing not only renders the air still around us, but it also regulates its temperature by the heat which leaves our body; we heat our garments, and they continually heat the air passing through the meshes and pores of the texture. We may compare our clothing to a calorifer or stove, warmed by the heat emanating from our body's engine for the purpose of warming the air round our surface.

We do not feel the loss of heat which our clothing undergoes as we should if the air were to strike our surface without having been previously prepared by our dress; the differences of temperature balance themselves within the material we are clothed in, and of which the ends of our cutaneous nerves form no part. Inside our dress we carry the air of the south wherever we may be. Its temperature averages about 75—94 degrees Fahr. We live in our dress like an unclothed tribe in a paradisian country, where the air is constantly calm and the temperature 75°—94°. It will be easily understood now, why rough loose textures keep us so warm, while newly carded cotton-wool does so more than when old and compressed, why tissues of fine fibres and threads make the best material. Fur, of

which you know so well the properties, consists of hair and skin. Chemically speaking there is not much difference between skin and hair. In fur the weight or body of the skin is much greater than that of the hair, and still it is essentially the light hair to which the fur owes its warming properties.

There are some interesting experiments on this point. *Krieger* observed the flow of heat after covering his cylinders with unshorn and shorn fur. Putting down the loss of heat through the entire fur as 100, he found that it rose to 190 when the same piece of fur was used shorn. A dried skin you know is always somewhat porous. When he altered this by giving it a coat of linseed-oil varnish the loss of heat rose to 258, and when he took a solution of gum arabic instead, it rose even to 296.

It has been proved that the living organism, in parting with its heat by radiation and conduction, behaves just like a tin-cylinder filled with warm water. It is a yet older observation that furred animals, such as dogs, rabbits, etc., cannot live when they are shorn and their skin varnished or oiled. One used to explain their death by the suppression of the evaporation from their skin, but it can be proved that even in a comfortably warm room these animals literally freeze to death. *Krieger* sheared a rabbit, after having noted its temperature and frequency of respiration; they were 102° and 100 per minute. He did not use any varnish, to avoid any possible suppression of evaporation from the skin, but enveloped the shorn animal in a wet cloth. The temperature of the room being at 66°, the animal lost so much heat that after five hours its interior temperature had fallen to 75°, and its respiration to 50 per minute.

A fur is so arranged that its fine hair projecting into

the air intercepts all the heat, which flows from the surface by radiation and conduction, and distributes this heat through the air, which circulates between the single hair-cylinders; the finer the hair of the fur, the more of the outgoing heat is taken up by the air, which, however cold the temperature may be, reaches the nerves of the skin as a warmed air. Furred animals, in winter, when touched superficially, give a very cold sensation, it is only near the skin that their hair feels warm. In severe cold certainly little of our animal heat comes as far as the points of the hair, from which it would radiate or be conducted into the air; the current of air in the fur cools the hair from its point towards its roots, and a severer cold penetrates only a little further into the fur, without necessarily reaching the skin of the same. This takes place only when the temperature is uncommonly low, and the air in violent motion. Travellers in high latitudes all agree that extreme degrees of cold can be borne very well when the air is calm, but scarcely so when there is a brisk wind.

This tends to show, that in very severe cold the outflow of heat by the skin into the air contained in the fur or within the dress, takes place through one route only, that of conduction; when a fur is worn, no heat comes to the surface for radiation, as soon as the points of the hair have the temperature of the surrounding air. Evaporation also sinks to a minimum, because at 68° F. under freezing point all formation of aqueous vapour already ceases, and nearly all the heat in the fur and the dress is employed to heat the arriving air, whose velocity increases according to the difference of temperature. In a well-furred animal the changes of temperature in the surrounding air only change, if I may say so, the latitudes of the cold and warm zones in the fur; the place where the temperature of the

body and the air equalise each other moves between the roots and points of the hair, and for this reason such a well furred animal is not warmer in summer than in winter. Its blood keeps always at the same temperature, because in summer a great part of its heat leaves at the points only of the hair by radiation and conduction, while in winter the heat departs already near the roots of the hair.

Airproof fabrics ought to have only a very limited use. In India rubber or gutta percha textures we feel highly uncomfortable when we have to undergo much exercise, or have to give off more heat than usual. They become inconvenient, not because they stop the change of air entirely—which they cannot do in fact, on account of the necessary openings in them—but only because they limit the universal exchange of air in the underlying garments. For protection against the wet from without they are well suited, but they produce another wet on our skin by impeding evaporation. They may be used in wet weather, when accompanied with cold or wind, but never, though wet, when it is warm or calm.

Finally, I have to draw your attention to the relations which the materials of our clothes have to water, by which their functions are considerably altered. They are all hygroscopic, that means that they condense from the atmosphere a certain amount of water. This hygroscopic property, very different in different bodies, increases with the decrease in the temperature of the air, so that all of them condense more water at freezing point than at higher temperatures. Partly, also, the relative moisture of the air is of some influence, so that at 68° the hygroscopic body absorbs more water from an air nearly saturated than from a less moist air. As yet we do not know much *about our clothing* materials in this respect. I have

made some preliminary researches, and have found unexpectedly great differences.

I took two equal pieces of flannel and of linen, as representatives of the two most important fabrics made of vegetable and animal fibres, and dried them at 212°, a temperature at which they lose all their hygroscopic water. I put them into well closed boxes of known weight, and noted the weight of the two together. They were then exposed to the air in places of different temperature, and from time to time put back into the tin boxes, and the weights taken again. By this method it was not difficult to ascertain the relative quantities of hygroscopic water, which the flannel and the linen had absorbed. These quantities are tabulated below, as they resulted from different localities, temperatures and lengths of time, the weight of the linen and flannel being 1,000 grammes each :—

Observ.	Locality.	Temperature.	Time.	Hygroscopic water in	
				Linen.	Flannel.
1	Cellar.	37.58° F.	12 hours.	77	157
2	Lecture-room.	34.16	„ „	74	143
3	Room.	64.25	„ „	41	75
4	Laboratory.	53.96	„ „	63	105
5	Cellar.	39.92	„ „	111	175
6	Lecture-room.	40.1	4 hours.	93	160
7	„	40.1	3 „	91	148
8	„	41.9	15 „	85	146
9	Room.	69.8	10 minutes.	73	113
10	„	69.8	„ „	52	96
11	„	70.7	„ „	45	87
12	„	70.7	„ „	43	82
13	„	68.9	15 „	42	78
14	„	68	„ „	42	77
15	„	64.25	30 „	41	75
16	„	62.6	1 hour.	48	76
17	„	61.7	2 „	45	77
18	„	59.9	—	46	78

What most strikes one, is the invariably greater hygroscopic power of wool than of linen; the maxima and minima of flannel and linen, being respectively 175 and 111, 75 and 41.

Observations 5—8 show that linen changes the quantity of its hygroscopic water at a proportionately quicker rate than flannel. The two pieces were for twelve hours in the cellar, when linen absorbed 111, flannel 175; immediately after, for four hours, in a cold place, where linen lost 18 per 1,000 of its absolutely smaller amount of water, while the flannel lost only 15 per 1,000; but during the next three hours linen lost only 2, but flannel 12 per 1,000.

When (Obss. 9—15) the pieces had come from the cold lecture-room into a warmed room, linen again ceased giving off water at a much quicker rate than flannel.

The accelerated rate, only in an opposite direction, took place again (Obss. 15—18) when the temperature in the room sunk from 65° to 59°.

All bodies become more hygroscopic with a sinking temperature, but the absorption of water and increase of weight, as well as the contrary process, take place proportionately quicker with linen than with flannel.

The more the air in any material is displaced by water, the less it keeps us warm, the quicker it conducts the heat; hence the frequent injury resulting from wet clothes, and the striking discomfort produced by a damp cold. You all know how comfortable we can feel in a walk, when the air is cold and dry, and how differently we feel when it is damp, although not colder. Then our clothes also get much damper, and conduct more of our heat away.

This is not to be underrated. We have seen in the

table, that 1,000 parts of flannel took up in the cellar 157 parts of water. Take the weight of a whole woollen clothing as ten pounds, and you see that it may absorb one and a-half pounds of hygroscopic water, which requires about 1,680 caloric units from our body to be evaporated.

Linen and flannel bear the same relation towards water they are wetted with, as towards their hygroscopic water. Linen is quickly wetted and soaked, wool more slowly, but linen cannot take up the same quantity. Spilled water has certainly taught you this many times, when you wanted to take it up. It is the same in evaporation, which is also much quicker from linen. Two equal pieces of linen and flannel, weighing each 1,000 grammes, put into water and wrung out till they no longer yield a drop of water, keep back respectively 740 and 913 per 1,000.

But a much greater difference exists in the intensity of evaporation from wet linen and from wet flannel, during equal periods, in a heated room.

Obs.	Temper.	Minutes.	Water to 1,000 grammes of	
			Linen.	Flannel.
1	70° F.	—	740	913
2	68	15	521	701
3	68	30	380	603
4	67	30	229	457
5	66	30	99	309
6	66	30	55	194

It is easy to see from this table, how much quicker linen works than wool in every direction.

During the first 75 minutes there evaporated from 1,000 parts of linen 511, from 1000 parts of flannel 456 water; afterwards the reverse took place: in the following thirty

minutes 130 evaporated from linen, 148 from flannel, and in the last thirty minutes only 44 per 1,000 from linen, but 115 from flannel.

It is also evident how much more evenly the drying proceeds in wool: in the first fifteen of the whole 135 minutes 219 evaporated from linen, in the last fifteen minutes 28 per 1,000, while with wool it was respectively 212 and 97 per 1,000. I must not forget to mention that all these experiments were made with pieces of nearly equal size and shape.

It is self-evident that all textures lose their permeability to the air in proportion to their state of humidity, the water partly at least obstructing the pores. Coarser stuffs with larger pores will keep their permeability longer; if the pores are equal, the difference in the adhesion of the water to the substances will come into play. Linen, cotton, and silk are very different in this respect from sheepswool. The former become very quickly airtight by wetting, the latter scarcely so, or only after a longer soaking. Soldiers can tell how damp and vaporous the air becomes under a wet tent, and how quickly the tent becomes airy, when it begins to dry.

As the porosity of all fabrics depends chiefly on the elasticity of the fibres of their material, it must be of great importance, how far that elasticity keeps under wet and dry. There, again, wool stands apart; its fibres do not lose much elasticity when they get wet: it is not so with other fibres. Wet linen and silk are just like Krieger's shorn fur, when it was coated with varnish or gum arabic. The greater facility of catching cold in wet linen or silk than in wet wool is in exact proportion to the greater facility with which water expels the air

contained in their fibres. Many of you may have learned a lesson from a wet linen or cotton and a wet woollen sock.

On the other hand, there is an advantage in these materials if we want to keep ourselves cool and dry. By means of them we part with heat and moisture from our surface much quicker, and hand them over to other layers for further removal.

To be quite methodical I ought now to treat of the different parts of our clothing and of the fitness of different materials for special purposes. But to say the truth, Science has not yet done much in this direction.

There is still one of our garments to be considered which generally is not considered as such. I mean the bed—that piece of clothing in which we spend such a great part of our time. It is equally indispensable to the sick and to the healthy, and at all times it was considered as a sign of bitterest want if a man had no place to lay his head.

The bed is not only a place of rest, it is especially our sleeping garment, and has often to make up for privations endured during the day and the day's work, and to give us strength for to-morrow. You know all the different substances and materials used for it. They are the same as our garments are made from. Like them, the bed must be airy and warm at the same time. We warm the bed by our body just as we warm our clothes, and the bed warms the air which is continually flowing through it from below upwards. The regulating strata must be more powerful in their action than in our day clothes, because during rest and sleep the metamorphosis of our tissues and resulting heat become less, and because in a horizontal position we lose more heat by an ascending current of air than in a vertical position, where the warm ascending

current is in more complete and longer contact with our upright body.

The warmth of the bed sustains the circulation in our surface to a certain degree for the benefit of our internal organs at a time when our production of heat is at the lowest ebb. Hence the importance of the bed for our heat and blood economy. Several days without rest in a bed not only make us sensible of a deficiency in the recruiting of our strength, but very often produce quite noticeable perturbations in our bodily economy which the bed would have protected us from.

I wish, therefore to impress upon you that your charitable exertions for the poor may become extended to the bed, that kind of garment which can make up to a great degree for other lamentable deficiencies, as in food, dwellings, clothing, towards which you are in the habit of directing your efforts.

I am quite aware that I have anything but exhausted the subject of the functions of our clothes, but still I believe that I have directed your attention to such essential points as to convince you of the importance which a scientific consideration of the subject possesses in the interest of the heat-economy of the human body.

As our health is so intimately connected with this economy a better insight into the laws and proceedings of the same must in the end turn out profitable to health in general.

Thus we have learnt in our last glorious war how important it is to provide well for the soldiers' clothing, and that a few days' want of provisions is less injurious to the health of the soldier than perturbations of heat-economy through want of suitable pieces of clothing. *Our clothes* are weapons with which civilised man fights

against the atmosphere as far as it is inimical, the means by which he subjugates this his element. It lies in our nature, in our instinct, in our self-respect to have good clothes, which ought to be also pleasing to the eye; but we ought to become more conscious of their purpose. Ornament must be the minor consideration, and the tailor ought not to hold his scissors as a sceptre over the hygienic purposes of all dress.

Our period strives after novelty in all directions, also after new forms and styles in dress, architecture, and so on, but nothing new will be created with our old points of view remaining. New points of view can only be gained by new and increased insight into the functions of the dress and the house. This function must determine the form, and will not be ascertained without theoretical study. It was not till we had mastered the theory of the overshot and undershot water-wheel that the turbine could be invented.

The influence of theory on practical development is much greater than is usually supposed and conceded. The discovery and settlement of the laws of Mechanics had to precede their application to engines, railways, steamboats, and so on. There would be no difficulty in showing why the great inventions of *Watt* and *Stephenson* were not made at an earlier period, and that they were the fruit of seeds which were buried in the theoretical investigations of *Copernicus*, *Kepler*, and *Newton*.

Perhaps our future means for keeping our heat-household will be as different in style and appearance from our present ones as a turbine from an old millwheel, or a steam engine from a horse-wheel. In my next lecture *I intend treating of the air in the house.*

SECOND LECTURE.

ON THE RELATION OF THE AIR TO THE HOUSE WE LIVE IN.

We shall devote this evening to the consideration of some hygienic functions of the house.* On the whole, the house has the same hygienic object as our clothing; it has not only to keep up the intercourse with the atmosphere surrounding us, but to regulate it according to our wants. No more than our clothing ought the house to be a contrivance for excluding us from the air outside. In some of their forms we can also trace a certain mutual transition. The cloak and the tent are cousins. The heavy circular cloak of former times might well be styled a portable tent, and the tent a fixed cloak; both have their necessary openings. So the hat may be considered the roof of our clothing, and the roof the head-gear of the house.

We may then naturally suppose that those materials

* In England owing to the manner of building, the smaller size of the houses, the open fireplaces and the bad fitting windows and doors, we suffer less from defective ventilation than in Germany, and although some other domestic arrangements, though far from faultless, are superior to those usually met with in Germany, nevertheless the general laws are the same, and ought to be generally *understood*.—Translator.

which are advantageous for the building of our habitations must stand in somewhat the same relations to air, water, and heat as the materials we use for our clothing. Walls allow air to pass through them, and they must do so to a certain degree if we are to preserve our health within them with some comfort and without injury. Current opinion is certainly opposed to my assertion about the permeability of walls to air, even more so than to that about the permeability of our clothing; but it is easy to show that current opinion labours under an error which has no other basis than the insensibility of our senses to the movement of the air, if the same is less than 19 inches per second. This is the cause of the fallacy that no motion of the air takes place. Just as well might we deny the earth's rotation round its axis at the rate of more than a quarter of a mile per second, because we are not in the least aware of this tremendous velocity. Only very late and slowly have our minds opened to the conviction that after all the earth moves round the sun, and not the sun round the earth, and that our eyes had all the while been mistaken. There must exist something of a higher nature, of a greater power than our sensuous perceptions, and that is Science, which examines and probes our perceptions. Science has not the least power over nature, she cannot command any alteration in nature, cannot give it any laws—she can only recognise the laws of nature. But Science changes the notions of man, and often reverses them. Ideas and notions based on Science enrich us, partly directly, partly indirectly with new means of making use of natural laws. It was not till Astronomy had found and determined celestial Mechanics that the human mind was enabled to begin that development of the mechanical element

which is the pride and the power of our period as compared with former times.

If, then, we are hopefully satisfied with endeavouring to increase our insight, our Science of the things that are, the benefit will not fail to come, and everything is beneficial of which man learns to make use. This requires time, often a very long time, as old experience teaches.

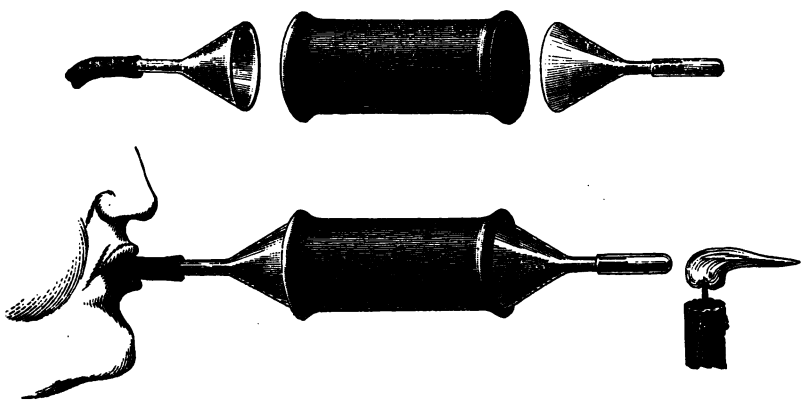
The task of Science is to lay hold of everything perceptible, and to penetrate it, the small as well as the great. The insect and its life is just as interesting to Science as the elephant, and therefore I believe that I may occupy myself with that air which flows through our walls, although its motion is not recognised by our sensations.

We may conclude from many facts that walls are permeable to air. No one maintains that houses have water tight walls, and everybody knows that masonry is easily penetrated by water. Wherever a wall is in perpetual contact with water it becomes so soaked that at last water comes out in drops on the other side. Certainly where water can pass air must pass much more easily, because air is 770 times more light and moveable than water It is very easy to construct watertight apparatuses and vessels, but very difficult to make them airtight. Still people are surprised when they hear of a change of the air through a wall; they see of course and feel the water in the wall, but of the air in the wall their senses have no direct perception.

But we have means to demonstrate to our senses the passage of air through our building materials—we have only to lead the air, which comes against some large surface of wall, into and through a narrow tube. I will *prove this to* you by experiments; but you have often

seen the same thing before, when you were looking at some piece of water, which had some small in- and out-flow. These may be in lively motion and driving-mills, but on the whole surface the water seems to be completely at rest. But if we do not see any water running in and out, we declare the whole to be stagnant, and we may be very much mistaken.

I have here a cylindrical piece of mortar, half lime, half sand, 5 inches by 1¾. The cylinder has been covered all over with melted wax, which is impermeable to air, with the exception of its two circular ends. You see this glass funnel, with a tube. I fix it on one circular end, where the mortar lies free, and make an air-tight connection by wax with the waxen coat of the cylinder. If I blow



through the tube, the air must appear on the free mortar end, provided the mortar is permeable to air. It has as yet no effect on the flame of this candle, because its velocity is not great enough. But if I fix a funnel on the other end of the cylinder, the air, which has passed through the mortar, can only escape through its narrow

end, and there you see the flame sensibly deviating. You may even succeed in extinguishing it altogether. The velocity of the air in going through the tube must increase in proportion as the transverse section of the tube is smaller than the mortar-surface, out of which the air escapes, exactly as with the water of the pond and its in- and out-flow. Now, when I dip the end of one tube into water, you see and hear the air, which has passed through the mortar, escape from the water. If you make a similar arrangement with a piece of wood, or a brick, you will see the same result.

Most kinds, also, of sandstone are so porous, that water and air easily pass through them. Solid or quarried limestones are scarcely permeable to air, but as they are mostly of irregular shapes, they require more mortar, and that is the reason why such walls are, after all, not so much more air-tight than walls made of regular bricks and thin layers of mortar. Observations have been taken of the average quantity of mortar used with different building stones. We may suppose that, taking the wall as a whole, it is $\frac{1}{3}$ with quarried lime, $\frac{1}{4}$ with tufaceous lime, $\frac{1}{5}$ to $\frac{1}{6}$ with bricks, $\frac{1}{6}$ to $\frac{1}{8}$ with cubes of sandstone. In practice, then, the quantity of the mortar rises with the decrease of porosity in the building stones, and assists in keeping the walls pervious to air to a certain degree.

It is self-evident that the quantity of air which passes through building materials of a certain thickness must increase in proportion to the surface; 2 square feet must give passage to twice as much air as 1 square foot. I shall speak of Ventilation in connection with this, later on.

The effect of wetting porous materials is quite surprising.

In proportion as the pores fill with water, they become impervious to air. The adhesion of water to stone and mortar is greater than that of air, by as much as water is heavier than air. It is not difficult to blow great volumes of air through dry mortar and dry bricks, but it requires a great exertion to drive a few drops of water through the same materials. You know this cylinder of mortar (see above). Instead of blowing air through it into water, I will suck the air out of it; you see now the water rise in the tube and wet the surface of the mortar. Now I'll try to blow again air through the mortar; I cannot, with all my exertions, because the pores of the mortar are filled with water.

This simple experiment lays bare the great hygienic disadvantage of wet walls: they are air-tight, not to speak of other injurious effects.

We all know that new houses are dreaded on account of their humidity. In some countries there are regulations by law, and new houses must be approved with respect to their dryness, before they may be let. But the notions about the causes of their humidity, and the means of removing it, are very different and discordant. Allow me, therefore, to explain how water gets into the new house, and how it is to be got out of it.

I need not call to your mind the first steps in a building operation, and how soon a connexion is made with some abundant source of water, and that a great deal of water is required for making the mortar, &c., &c. Let us now try to come to an estimate of this quantity of water.

Suppose that 100,000 bricks were used for a building each weighing 10 pounds. A good brick can suck up more than 10 per cent. of its weight in water, but we will put down at 5 per cent. what gets into it by the manipula-

tions of the bricklayer. We will assume that the same amount of water is contained in the mortar, a quantity certainly much understated, and that the mortar forms about $\frac{1}{5}$ of the walls: we have thus 100,000 pounds of water, equal to 10,000 gallons, which must have left the walls of the house, before it becomes habitable.

The two principal ways in which wet or damp walls are injurious are: 1. By impeding ventilation and diffusion of gases, through their pores being closed up or narrowed by water. 2. By disturbing the heat-economy of our bodies. Damp walls act as bodies abstracting heat in one direction: they absorb heat by their evaporation, and act like rooms which have not been warmed thoroughly; they are better conductors of heat than dry walls, just like wet garments, and considerably raise our heat-losses by a one-sided and increased radiation. Diseases which are known to be often caused by cold, are particularly frequent in damp dwellings—rheumatism, catarrh, chronic Bright's disease.

What can we do to get rid of that immense quantity, of these 10,000 gallons of water, before we remove into the new house? All this water—we cannot make it run off, we cannot squeeze it out, we cannot boil it away—it must take its leave in one way, a very safe but rather long one, that of spontaneous evaporation into and by the air. The capacity of the air for receiving water depends on the different tension of the vapour at different temperatures, on the quantity of water already contained in the air flowing over a moist body, and finally on the velocity of that air. For the first two moments let us assume the average temperature of the year to be about 50° F. and the average hygrometric condition of the air to be 75 per cent of its full saturation. Under these con-

ditions, one cubic foot of air can take up four grains of water, in the shape of vapour, but as it contains already 75 per cent. of these four grains, which amounts to three grains, it can only take up one additional grain. As often then as one grain is contained in the 10,000 gallons of water mentioned above, as many cubic feet of air must come in contact with the new walls, and become saturated with the water contained in them; or about 700 millions cubic feet of air are required to dry the building in question.

I will at once pass on to the consideration of a subject, some of you may be acquainted with already by experience, I mean the re-appearance of damp in new buildings, which had seemed quite dry, after they had become inhabited. There appear damp spots on walls and in corners, the panes in the windows sweat and the air becomes musty and oppressive. How does this water return, after the house has been declared and considered dry? Most people, because they see it only then, suppose that there is a new formation of water in the wall, or that it was set free by the presence of the new dwellers. Here again our sensuous perceptions mislead our judgment, and give us no clue as to the circumstances under which moisture in the walls becomes visible to our eyes and humidity produces a damp spot. I produce here a piece of brownish-yellow paper of somewhat indistinct tint. Where I wet it with water, the colour appears more intense, darker even, just as if the water had been coloured. Now the paper is getting dry again, and the former appearance comes back.

Some of you may laugh at me for making such a trivial experiment, but I beg to ask, what is the reason of this action of the water? It takes place only on porous or colours or coloured substances which are porous, only on

Aquarells or Frescos, scarcely on Porcelain or Glass paintings. If the water cannot penetrate into the colour it cannot alter its appearance any more than that of a colourless transparent glass.

Oil paintings, when they are new or lately varnished, are in this respect like Glass paintings, but when they get older, some of the colours, by the longer action of the air, get dull, and then water has the same effect on them, as on this paper. It gives them a fresher appearance, till it has dried away. This is because all oil colours become porous in the course of time.

For water to penetrate thus into the colours, we are entitled to assume that there must be free spaces within them to receive it, pores and interstices. These cannot have been vacua before, but must have contained air. This air in the painted surface is displaced by the water, and hence the difference in the optical effect. Air and water have different optical properties. In the first instance our colours—dry and dulled—are mixed with air; in the second instance with water. Water refracts, disperses and reflects light quite differently from air, therefore it must have quite a different effect on colours, when it gets admixed with them instead of air. The whole question has been more fully treated by me in a little treatise on Oil-colours and the preservation of Galleries; * it may suffice here and for the present to know that damp spots on a wall can appear only when the pores are filled with water or some other transparent liquid. Our sensations have rightly taught us to associate the words dry and airy, damp and confined.

If we have moved into a new building too soon, we

* Appendix.

may be deceived by its appearance. It is quite possible that the walls have become sufficiently free from water and full of air, for the colours of the papers and walls to appear mixed with air, and free from all interstitial water —still we are not entitled to suppose that all water has left the walls. A good deal may remain unnoticed, provided some air is lodged in the pores of the surface sufficient to produce the optical effect of real dryness.

How does it, then, happen, that on receiving their complement of inhabitants, the pores of the new walls become obstructed, partly or locally, by water? The ordinary explanation is completely erroneous, although it sounds quite scientific and rational, and has its place in books and lectures on Chemistry. It is stated, that it is the effect of carbonic acid on the hydrate of lime which remained in the mortar. Mortar is a very interesting object, and I regret that I cannot enter more fully into its nature and process of hardening. I'll tell you so much, that the burnt and slaked lime used for its preparation is a compound of lime (oxydised calcium) and water, the above mentioned hydrate of lime. This, by the action of the air, is changed into carbonate of lime. This change takes place at first very rapidly, and to the extent of about one-half, but then slower and slower, so that in very old masonry one finds frequently some of the original hydrate of lime. This is a perfectly dry substance, which yields none of its water to air, which is dry and free from carbonic acid. When changed into carbonate of lime, the water, which as a hydrate it contained, chemically combined, is set free, while the lime and the carbonic acid combine. This water is commonly considered to produce the damp spots which appear here and there in new buildings. It has been imagined that the respiration of the new inmates

increases the amount of carbonic acid in the air and accelerates the process, setting free the water, which renders the wall damp and chokes up its pores.

This explanation is not based on any single direct observation made on the wall itself; it is nothing but a specious conclusion. Although hydrate of lime exposed to air, which contains carbonic acid, changes into carbonate of lime, no one has ever found it becoming moist. The liberation of the water, however, much it may be accelerated in the indicated way, is unable to refill the pores of the wall, which were supposed to be already filled with air. To do this it would be necessary that the water in the hydrate should not have occupied any space, or that, when set free, it underwent such an expansion as water becoming a gaseous substance. All scientific analogies and observations protest against this. Changes of solid into liquid bodies take place without any considerable increase of volume; it is different with the transition of liquids into gases, when the increase is very considerable.

It is only by the complete choking up of the pores by water, and the complete expulsion of the air from the surface of the wall, that the damp spots can be formed; and the freed water of the hydrate, which can not fill a space which it had not filled while in its former combination, can not do this. So the absorption of the carbonic acid is unable to produce the required increase of volume.

The fresh spots in new buildings can only arise from the precipitation of water from the air on the walls.

The inhabitants of a house give rise to a great amount of watery vapour, not only by the functions of their lungs and skin, but also by the numerous manipulations of the household, such as cooking, washing, cleaning, &c.

If the air in the house is already saturated with water in proportion to its temperature, a small degree of cold in the wall is sufficient to produce a dew, a precipitation of water from the vapour, just as one sees it on window-panes. But the porous wall can imbibe a good deal, and in old buildings, we may see the windows sweating profusely, while the walls seem to remain dry. It may last a long time before a well-constructed wall or partition gives any sign. They go on condensing water till their pores are filled and all the air expelled—then, not slowly and gradually, but all at once, numerous damp spots make their appearance.

It is, therefore, clear why those youngsters of houses are so much more subject to damp spots than their brethren of more mature age. Their walls have lost just enough of the building-water to allow the air to occupy part of the pores; optically, they seem dry, but still very little water is required to choke up the pores here and there anew, and wherever this takes place the spots break out. The effect of a fire is very instructive; nothing produces damp spots so easily in a fresh building, as the first fire, when doors and windows are well closed. The heat from the fire begins by heating the places nearest to it, and a good deal of water evaporates, so that the air in the room must come nearer its point of saturation. But at a distance from the fire, the walls being colder than the air, dew falls, and if the pores still contain great quantities of the building water, they soon begin to overflow.

Another proof that the water chemically combined with the hydrate of lime is not able to fill the pores when it becomes liquid, lies in its proportionately small quantity. A house built, let us say, with 100,000 bricks, contains,

at most, about 33,000 pounds of burnt lime. This cannot combine with more than about 10,000 pounds of water in becoming a hydrate. By the time the mortar is hard and set, and the building becomes inhabited, probably one half of the lime has become a carbonate, and there remain only 5,000 pounds of water in the remaining hydrate, which is 5% of the whole mass of 100,000 pounds of water which got into the new building during its erection. If, then, the other 95% of the building-water were gone, the 5%, or even 10%, remaining, or formed by the change of hydrate into carbonate of lime, would not produce the optical phenomenon of dampness.

I have dwelt somewhat longer on this subject, because it is indispensable for a correct view of the function of the wall: the removal into the open air of a great part of that watery vapour, which develops itself in every human household. Our walls have to swallow a good deal of that vapour as water, and to pass it on through their body, that it may evaporate on their outer surface. That is the reason, why localities looking to the north, or shaded from the sun, are so much damper. This appears most clearly in unheated places, chiefly at the transition from winter to spring, when it is warmer outside than inside. We are glad to have once more the windows open, to let the tepid spring-air gladden the cold interior; but a good deal of water will soon be seen deposited on the walls and the objects within the rooms, which has to evaporate just as from a new building.

You are now well aware of the usefulness of porous building materials, they alone can make dry dwellings. I cannot help thinking badly of all the substitutes for wood, brick and mortar, which have been proposed, as zinc, iron, putty, &c. Perhaps the natural functions of

the mortar-wall may one day be efficiently exercised by something else: for the present it has not been done, and will not be done as easily as many so-called practical people suppose.

Let me just relate to you a case, which shows, that without a correct view of the functions of walls, an apparently excellent plan may just produce the reverse of what was intended. In the neighbourhood of iron-smelting works, the slag is often used for building purposes. This material, associated with other stones, does very well. As it exists only in very irregular shapes, it requires large masses of mortar, and in our case this was believed to be undesirable. So it was decided to take only large regular pieces for the erection of a large workmen's dwelling, by which means the application of mortar could be reduced very much. It was a pleasure to see how quickly the building proceeded, and how much more quickly it got dry and habitable than other buildings, where irregular pieces and much mortar had been used. As soon as the workmen and their families began to live in the new building, the traces of damp began to show, and at last the house became the dampest in the whole establishment, and remained so. The thin layers or bands of mortar could not dispose well of the water, which was deposited from the air in the house, and this was the worse, as the slag is not like brick and mortar, which suck the water up, but is a vitrified substance, on which water precipitates as on a window-pane.

But how are we to judge in a given case, whether a house is sufficiently dry? No doubt, in every locality a practical experience establishes itself, founded on the knowledge of the usual material, the manner of building, and the climate. But if as in some countries, some

authority has to declare a house dry and habitable before it is to be let, there will be no end of disputes between this authority and the proprietor, because, after all, apart from the age of the building, the verdict of the experts will be given on their subjective view, not on definite and palpable signs. You know, already, that the absence of damp spots means very little. Feeling by the hand the temperature of the walls, knocking at them with a little hammer, are all of not much good. Not a bad plan is to get from different places in the house small pieces of mortar and to have them examined as to their contents of evaporable water, which ought not to be more than 5 per cent. of the weight. But we may have fallen just on dry places only, and get considerably deceived. Direct and comparative hygrometric observations would be best, but the necessary preliminary researches for this kind of examination are still to be made.

But what is to be done if a new building is to be brought quickly and surely into a condition of dryness? I have been obliged to shake your belief in the one means which appeared to exist, the development of carbonic acid by burning charcoal in basins, or open stovès. But I shall try to give you something in exchange for what I have taken from you. This something is nothing but an appeal to what we have learnt above. There are no means of removing the water from a fresh building but by letting it evaporate into the air. This evaporation, you know, depends on the temperature, the humidity of the air, and its velocity.

Imagine to yourselves a moderately-sized room of 3,530 cubic feet, and the temperature and humidity of the air at the above given mean averages. As 1 cubic foot of such air is capable of taking up 1 additional grain

of water, the air of the whole room will take up 3,530 grains, or about ½ a pound of water. Should there be no change of the air, matters would remain so. But by every fresh 3,530 feet of air coming into the room another ½ pound of water would be taken up, and so on. Suppose the change amounts to 353 cubic feet per hour, all the moisture we get rid of per hour would be only 353 grains per hour. But if we heat the room to 68° Fahrenheit, for instance, we increase the tension of the vapour, *i. e.* the capacity of the air for taking up water from 4 to 7 grains per cubic foot, so that each cubic foot of fresh air entering the room, is capable of taking up 7 instead of 4, that means 4 grains in addition to its original humidity. In consequence of this increased capacity, the 353 cubic feet of air take up 1,412 instead of 353 grains of water. But by the increased difference of temperature between the room and the open air, ventilation rises from 353 to 2,100 cubic feet per hour, and in this way we get rid of more than 20 times as much water, as if we left the room unheated.

All kinds of stoves and charcoal-dishes act only as sources of heat, and not as sources of carbonic acid. The only rational and efficient way is the *heating of all the chimneys and stoves, and the continual ventilation of all the rooms.* All other ways are of no use, or deceptive.

You have seen that the wall has its Physiology, a life of its own. Perhaps you will no longer find it so strange, that Master Quince introduces not only a pale moonshine and a rough lion, but also a "sweet and lovely wall" as a living and talking person. I had many things more to tell you about the wall, but I have still another subject of special importance before me—the change of the air in the house, or ventilation.

We have seen already, in speaking of our clothes, that the well-being of our body requires a continuous current of air to flow round us, and for the same reason a flow of air must take place continually from the open air through our dwellings. It used to be a current belief that in the still air of our houses, we were separated and shut off from the external air. You know that this error arises from our nerves and senses believing the air to be quite calm and motionless, although there may be some movement. We must be thankful to our Creator for this our error, else we should probably have ceased to exist. However anxious we may have been to shut ourselves up from the external air, we still remain in connection and intercourse with it. No house can have an atmosphere of its own, it has that by which it is surrounded, which travels and flows through it slower or quicker, while the house, and whatever exists and goes on in it, have no other power than to render this air more or less impure.

This pollution must not overstep a certain line, and this line depends on the proportion between the pollution and the change and volume of the air-current.

We change and pollute the air within our houses in two ways, 1, by admixture of substances, which were not in the air when it came to us, and 2, by changing its normal composition. Both are unavoidable, but there are limits, which must not be overstepped. The impurities may be in the nature of gases, or dust. We often become aware of them by our senses, by sight, by taste, mostly by smell. The last sense is exceedingly sensitive for many substances, for instance, traces of ethereal oils. Nothing is more wonderful than its acuteness with some savages and animals. If we consider the minute*ness of* the substances left by hunted game on the soil,

which it scarcely touches in its flight, and how the dog detects them even a long time after, we cannot sufficiently admire such a performance of the sense of smell. Other substances make themselves known in other ways, sometimes by some physiological effect. Oxyde of carbon, for instance—a gas which is generated from burning charcoal—is not perceived by any of our senses, but if it is present in air to the extent of $\frac{1}{2}\%$ only, it destroys human life after a while. A few grains of veratria, rubbed down into a powder, will set all the persons in the room sneezing. Other substances, as the products of distillation of fats, or the smoke of wood, irritate the membranes of the eyes. Other vapours and kinds of dust act on the taste, for instance, aloe powder.

We rightly consider all air, which acts on our senses or our feelings differently from air in the open, to be polluted.

The second way, in which we render the air impure on its journey through our houses, is that of altering the quantities of its compounents. We deprive it of Oxygen by our respiration, by the burning of lights and fires, we increase its carbonic acid and its water by the activity of our lungs and skin, and by numerous proceedings of the household.

All these pollutions and alterations are partly avoidable, partly unavoidable. Among the latter, are those by our lungs and skin, because we cannot live without producing them. To the former belongs everything, that from want of cleanliness, careless treatment of waste and refuse, passes into the air-current, the utilisation of which ought to be the privilege of our skin and lungs. It is an inexcusable waste of ventilation, if it is directed against avoidable pollutions of the air, besides its being

generally of not much use for this purpose. If I had a nuisance in my room, I should be a fool if I kept it there and trusted to stronger ventilation. The rational way is to do away with the pollutions, not to keep them and to fight them by ventilation. Without strict cleanliness in a house or public institution, all contrivances for ventilation will not do much good; the proper domain of ventilation begins where cleanliness by rapid removal or careful shutting up of air-polluting substances has done its best. It is only against the deterioration of the air by respiration and perspiration, which is beyond the control of cleanliness, that ventilation can direct its power, and against this deterioration this power must be chiefly directed.

Let us now consider the different causes of the motion of the air. As air in motion is wind *(ventus,* Lat.), ventilation is a better expression than "airing." Anything which disturbs the equilibrium of a body of air, produces motion in it. Its immobility supposes equality of temperature and specific gravity, and also of mixture in quantity and quality. Such conditions, as you may suppose, are seldom present, and absolute calmness is impossible. Different kinds of gases tend to intermix in every direction, even contrary to their specific weight, a process which is called diffusion; but this kind of motion is not in question, when we speak of ventilation. Ventilation means the setting in motion of masses of air by mechanical pressure and the dislodging of whole bodies of air similarly composed, which for that reason are not subject to diffusion.

We produce ventilation by disturbing the equilibrium of the air in two ways: 1, by producing differences of *temperature* between two neighbouring bodies of air,

which are accessible to each other; 2, by mechanical pressure on or driving off the air in a certain direction. We cause the same motion in either way, but the first we call *draught*, the second *wind*; we call forth a draught by a chimney, we produce a wind by a fan, a fan-wheel, etc.

These two factors of change of the air are continually active in our houses, but to a very different extent at different times. Our houses stand in the open air, which is never quite calm; even if it appears so, there is still some imperceptible motion, some wind disposable for ventilation. Then our houses are either colder or warmer than the surrounding air. They act just like large chimneys. If they are colder, the air which comes in contact with them gets colder, and a downward air-current is produced; if they are warmer, the air gets warmer, and an ascending current is established.

It is evident that the intensity of the change must also depend on the way in which the house is shut up, on the size and number of its apertures, and the porosity of the materials it is built with.

For this reason a certain amount of ventilation is always taking place without any special arrangement for it, but its strength depends—1, on the amount of difference of temperature between outside and inside; 2, on the strength of the wind or air-motion in the open; 3, on the size of the apertures which are open to the change of the air. We may call the first two the air-motors, the last the air-mediator or janitor, doorkeeper; to a certain degree they can take each other's place. If there is not enough difference of temperature, as, for instance, in summer, the wind can act; if both together are too weak, opened doors and windows can help. In winter, when

the difference of temperature between the in and out-door air is considerable, small openings allow the passage of as much air as large openings during summer, because the difference of pressure is greater. When, in winter, we stay in an unheated room whose temperature is only slightly about that of the outer air, ventilation is quite as weak as in summer; the air, if the windows remain closed, becomes quite as bad by our presence, and we ought to air the room as in summer, but we do not, because we want to protect ourselves against the greater outside cold. The dwellings of the lower classes present frequently, during the greater part of winter, this form of defective ventilation, which gets worse with the length of the cold season. In the beginning the walls are still dry and porous, and assist the ventilation, so far as the wind helps them to do so; but in proportion as they get colder, they increasingly condense water from the air of the house, and finally become so choked up with it that they allow no air to pass, as you have seen in our moistened piece of mortar. Bad doors and windows, unmended window-panes, remain often the only routes for ventilation. Poor people, in complaining of them, are not aware that they are the smaller of many evils, and a defect without which they might suffer still more.

Many of you, on hearing this, may be gratified by an unexpected personal satisfaction. Those who try to alleviate the poor man's winter by gifts of fuel, not only procure for him the benefit of a warm room, but also of a better and purer air in this room. You may consider this as a scientific parable, showing that in each benevolent action there lies a further blessing, even if we had not intended it.

It follows, from these fundamental principles of ventila-

tion, that a great mistake is sometimes made in large dormitories. In the morning the custom is to open the windows, and to let them remain open all day long, to be closed only just before bedtime. The poor sleepers fancy that they are sleeping all night in a pure air. Whoever has occasion to enter such a place in the morning, before rising-hour, starts back before this pure air, which had only been renewed during the night partially and accidentally, and is so loaded with all kinds of animal emanations, that it presses with all its power on the fresh comer. If there is no sufficient difference of temperature between outside and inside, a partial opening of the windows during a winter night is just as necessary as during a summer night, as far as regards the change of the air.

The bodies of the sleepers are certainly a small source of heat, and such large sleeping-places become somewhat warmed by the human heat flowing from the beds, but they can never be warmed through and through, so that the walls could become warmer. The water-vapour exhaled by the sleepers condenses against the walls, and goes on obstructing their pores till morning. A part of this water may evaporate during the time that the windows are kept open, but it will be only a part, and hence the frequent breaking out of damp spots in such dormitories in the course of the winter.

There was a belief that sleeping in the cold was a good thing; but I cannot find any facts proving this theory, particularly no comparative observations about the wholesomeness of heated and unheated dormitories. It would be safer to say that experience proves that sleeping in the cold does not, generally, do harm. If a single person sleeps in a large cold room with shut doors and windows,

it will do him no harm when he has a good bed. One person cannot deteriorate the air of an unventilated space as much as two, or more. The bed is a garment, an apparatus, which is of great use for our heat-economy; it prevents our feeling cold even in the coldest dormitory, but the bed is no ventilating apparatus, and ventilation must be provided for in another way. He that wants to sleep safely in the cold, must have a good bed and a large space, or bad windows and doors, or very porous walls, or he must keep his windows partly open in winter, as well as in summer.

You have probably now the desire to hear from me how much air or ventilation a person wants in a stated time. After you have all the while heard from me that everything is full of air, that air penetrates everywhere, and that it is extremely difficult to prevent its passage, many among you will ask, What need is there of special contrivances, if the air passes through each brick, through mortar, through wood? Would it not be rather desirable, to protect ourselves against this universal aggression of the air?

It is with air, as with all things which we must have—as with money, of which we must not only have some, but sufficient—one must have as much as one requires. Some money is, after all, in everybody's possession, even that of the poorest beggar.

Till some time ago, ventilation was chiefly considered in its qualitative aspect; we wanted change of the air, and were satisfied if there was one aperture for it to go out, and another to come in. The question about the quantity of this air was never put; if it had been known how much was really wanted, and how it was to be procured, that amount of ventilation which was often paraded would

have appeared beggarly. It is only during the last twenty years that we have acquired clear ideas on this subject.

We deteriorate the air of a closed space inevitably by using it for the maintenance of our respiration and perspiration. To which degree, then, may we alter or pollute by our emanations the air of a closed space, without going so far as to injure our health? This leads us to another preliminary question—What standard have we for measuring the deterioration of the air?

At all times people have been in the habit of making some estimate of the pollution of the air by the smell imparted to it by the respiration and emanations of the persons staying in it. This estimate is of the same value as that we have spoken of when on the subject of the water in the walls. The smell of a certain air need not be in any kind of proportion to the use which has been made of it already for the purposes of respiration and evaporation. Besides, smelling is a very subjective sensation, of very different excitability in different persons. Although generally a certain rule for judging the air of a room may be based on its smell, the decision, in doubtful cases, will always be a subjective one. It would be a different thing if we could lay hold of the smelling particles in the air of the room, and measure or weigh them, and compare them with the volume of air they were taken from; but we have no method of doing this; everything is left to our noses.

For this reason I considered it indispensable to look about for some means which would make us independent of our subjective estimate. I started from the excretion of carbonic acid, as it takes place from the living human body; its quantity in the air can be ascertained easily

and accurately. There is some in the open air, although very little; the question was, therefore, to find out its increase in a number of inhabited rooms, with notoriously good and notoriously bad air, and to draw a comparison. The correctness of this proceeding depends on the supposition that there are no other sources of carbonic acid but the inmates, that there are no burning flames, or tobacco smoking, &c. I will not say that I consider the detected carbonic acid as the principal drawback to such air; it is, in my mind, the measure only for all the other alterations which take place in the air simultaneously and proportionately, in consequence of respiration and perspiration; its increase shows to what degree the existing air has been already in the lungs of the persons present. All other functions in which the air participates, keep in some proportion to the respiration.

A series of examinations have resulted in the conviction that one volume of carbonic acid in 1,000 volumes of room air indicates the limits which divide good from bad air. This is now generally adopted and practically proved, always provided, that man is the only source of carbonic acid in the space in question.

Suppose there is a known source of carbonic acid, the determining the amount of it in a room can also be used for measuring another element, which would otherwise defy calculation, I mean the amount of ventilation of a closed space of definite construction. Imagine to yourselves a room with its walls, windows, and doors, its numberless penetrable places through which the air holds ingress and egress. It is impossible to measure the velocity of the air at each crack, to measure each little hole, the diameter of each pore, even if one had the means of measuring such minute velocities and sections:

yet still we should like to know how much air changes in a given space and under different external circumstances. The only way appeared to me to be to mix the air of the room in question with carbonic acid to a certain degree, then to break off this mixing, and to observe the decrease of the acid in proportion to the air in definite times. Knowing the amount of the acid in the external atmosphere, we can calculate how much of the latter must go on mixing itself with the room-air, to which carbonic acid has been added, in order that the proportion of the acid may decrease by so and so much in a definite time. The action of diffusion or absorption may generally be left out of consideration in this calculation. I do not consider this method to be absolutely correct, but I have found it quite satisfactory when a building was a few years old and quite dry. At all events, until a better method has been found we must keep to this one, even if it were still less complete than it is.

By researches which are too complicated to be explained in a popular lecture, it has been found that the ventilation of the same room or space, when the doors and windows are shut, undergoes considerable and definite alterations under different circumstances. Ventilation has been found to be much greater than had been supposed before. On an average, in spaces in which the air kept good, there existed a ventilation of more than 2,100 cubic feet per head and hour. It is known that a person does not inhale and exhale more than 18 cubic feet of air per hour, and so it was thought that 2,100 cubic feet per hour was a ridiculously large quantity for one person.

But it has been shown, first in France, not by calculation, but quite empirically, by simple experimenting,

that this quantity of ventilation is not more than is absolutely indispensable. After the epidemic of Cholera of 1848, the erection of a model hospital in the Faubourg Poissonniere was decided upon, and the Hospital la Riboisiere was erected, which was to be furnished with artificial ventilation. The quantity of air, which was required from the ventilating apparatus, was stated in the plan. It was believed that the demands put under Nos. 4, 5, and 7 of the plan for ventilation were extraordinarily large.

4. Continuous ventilation of warm air in winter and cold air in summer, at least 700 cubic feet per hour and bed in the large wards.

5. Ventilation during the day only at 350 cubic feet per bed, in the rooms of the corresponding pavilion.

7. The ventilating apparatus must have a surplus of strength, in order to be able to produce in all or some wards a ventilation double that stated.

The air was partly propelled by fan-wheels, partly by ventilating-flues. It flowed to and fro through pipes in the wards, and its velocity could be measured easily by anemometers.

In preliminary experiments, a ventilation of 350 cubic feet per bed and hour was tried, but the air was found already by the smell to be so bad, that the authorities congratulated themselves in having provided for double the strength. This was now tried, but with the same result, and it was a comfort to know that for extraordinary cases another 700 cubic feet per bed and hour could be obtained. But then also the state of the air was anything but desirable. It was only with 2,120 cubic feet that the medical and other authorities found themselves satisfied.

At present the demands for ventilation in France sound

very different from what they were about 20 years ago. They are now per hour and person :—

Hospitals for ordinary cases	2,120—2,470 cubic feet.
„ wounded	3,530 „
„ epidemics	5,300 „
Prisons	1,766 „
Workshops, ordinary	2,120 „
„ unhealthy	3,530 „
Barracks, day	1,060 „
„ night	1,410—1,765 „
Theatres	„ „ „
Large rooms for long meetings	2,120 „
„ „ „ shorter „	1,060 „
Schools for children	424— 530 „
„ „ adults	880—1,060 „

Such are the changes of times.

Now the many crevices, holes, and pores in our dwellings will no longer be considered by you as unlimited means of change of the air; since you know how large that change has to be, you will rather feel anxious whence to procure such enormous quantities, when you sit quietly within your four walls, where you do not fell the least draught, where no curtain moves and a feather lies quietly on the floor. This sensation of calm we owe to the insensibility of our nerves—*and yet the air moves.*

In order to give you some idea of the influences of differences of temperature, of more or less well shutting doors and windows, of a fire in a stove opening into the room and of the partial opening of a window, I will give you shortly the results I obtained with the aid of the carbonic acid measurement. The room had brick walls, and its size was 2,650 cubic feet.

With a difference of temperature of 34° F. (66° in and

32° outside), the contents of the room changed once in one hour, equal to 2,650 cubic feet.

With the same difference, but a good fire in the stove, whose communication with the chimney was made as free as possible, the change of the air rose to 3,320 cubic feet, or about 25 per cent. When all openings, crevices in windows and doors, were thoroughly pasted up, there was still a change of 1,060 cubic feet per hour, or a fall of 28 per cent. With a difference of temperature of 71° in and 64° outside, the change amounted to 780 cubic feet only per hour. When opening a window of 8 square feet, the change rose to 1,060 cubic feet per hour. These quantities are instructive. They show that a difference of temperature of 34 degrees, with carefully shut openings and crevices, is of greater influence than large communications with the outer air at a small difference of temperature.

The roaring fire and the draught of the stove produced only an increase of 700 cubic feet, one-third only of the necessary ventilation per head. I have examined a number of stoves opening into the room for the quantity of air which they abstract, while the fire burns. The anemometer showed that it was never more than 3,105 cubic feet. Large wards in hospitals, schools, &c., heated by one open fireplace or stove are sometimes wrongly believed to be well ventilated, because one perceives the air rushing into the same. But the main point is to know the quantity of required air and the quantity of outgoing air.

The free wall of a room of mine has been examined for its ventilating power. The room contained 2,650 cubic feet, and at 9/5° F. difference of temperature between outside and inside, the spontaneous ventilation through

each square yard amounted to about 7 cubic feet, or 43 gallons per hour.

Märker and Schultze, in their researches on the spontaneous ventilation of stables, have found for one square yard of free wall, at 9/5° F. difference of temperature, that the spontaneous ventilation amounted per hour

With walls of	Sandstone	to	4·7	cubic	feet
„ „	Quarried Limestone	„	6·5	„	„
„ „	Brick	„	7·9	„	„
„ „	Tufaceous Limestone	„	10·1	„	„
„ „	Mud	„	14·4	„	„

Domestic animals, according to Märker, require a proportionately smaller change of the air than man. Stable-air may contain up to 3 per mil. carbonic acid. While men's ventilation requires 2,100 cubic feet per hour, 1,050 are sufficient for full-grown cattle, although their bodies and consumption of air are so much larger. The ventilation of stables depends chiefly on the size and porosity of their free walls. It has been found that the 1,050 cubic feet mentioned above were furnished by

21·16	square	feet	of a free	wall	of Sandstone
15·33	„	„	„	„	Quarried Limestone
12·6	„	„	„	„	Brick
9·7	„	„	„	„	Tufaceous Limestone
7	„	„	„	„	Mud.

A stable built up of mud can therefore shelter many more animals than one built of sandstone, etc., etc. "As the strength of the natural ventilation of a stable does not depend on the cubic space of the stable, but on the extent of its ventilating walls, it follows that in a small stable a proportionately greater ventilation takes place than in a greater one, because for each animal there is more ventilating surface with equal cubic space."

This proposition naturally applies also to human habitations. The air will be better in a small family house than in large barracks; better in a cellular than in a common prison, where the day and night wards are large but crowded.

The question arises, what is to be done in all cases in which the natural ventilation of the inhabited spaces proves insufficient, and allows the carbonic acid to become more than 1 per 1,000? I might tell you now of the different systems of ventilation, the contrivances and apparatus belonging to them; but this is not feasible without models and designs. And after all, there would be no new principles or natural laws to acquaint you with. I believe I have made you sufficiently aware of the fundamental facts and conditions as to the change of the air in our dwellings, so far even, that you are now able to judge for yourselves, whether a certain plan for ventilation is rational or not. We have no other motors for changing the air, but differences of temperature and motion of the air, which we can call forth either by heat or by the motion of wind-fans—or which we must make use of as far as they are pre-existing in the atmosphere surrounding the house. By these two means we can produce certain perturbations in the equilibrium of the air-columns, and through this certain degrees of velocity in the motion of the air.

If we know the transverse section of the inlets and outlets, we have only to multiply their surface by the velocity of the air, and this will give the cubic quantity of the air which flows through the channels in a certain time. If we know the required quantity of air and divide it by the transverse section of the channels, we get at the velocity of the air in the channels. We ought not to

establish a greater velocity than 9 feet per second, it is better to enlarge the channels. These quantities must then be compared with the air required by each person, a quantity with which you are now acquainted.

If you take up the question of artificial ventilation in its quantitative aspect, you protect yourself at once against a series of errors into which else you easily fall. Our ordinary dwelling-houses need not be ventilated artificially; we ought never so to crowd them, that the natural means of ventilation, as difference of temperature, motion of the air in the open, dry, and porous walls, and temporary assistance by the architectural openings, are insufficient to keep undeteriorated what is most essential for our health. With these means there must go hand in hand the greatest cleanliness in all parts of the house, and abstention from all superfluous and avoidable pollution of the air of the house.

Before concluding, I am desirous of considering with you an expression which is in general use, but the frequent cause of wrong views about the change of the air. I mean the word *Draught*. All kinds of complaints are habitually ascribed to it, and the danger of draughts is one of the few hygienic principles which have become thoroughly popular. Perhaps this was not all profit, because with many people ventilation and draught are synonymous; they are afraid of a draught coming from an open window, an open door, and find themselves in collision with ventilation.

There is certainly and frequently danger in being exposed to a draught, a danger which has, perhaps, been over-estimated, because men have an irresistible desire to fix a certain cause for a certain evil. All collision is avoided if the proper meanings of *ventilation* and *draught* are thoroughly understood.

Ventilation is the necessary change of the air in a closed space, at which the velocity of the air is still taken for a complete stillness, and its motion takes place all round our body. It must not be more than a little above 19 inches per second.

Draught is a one-sided cooling of the body, or some part of it, frequently caused by a corresponding motion of cold air, but also in other ways, as by increased one-sided radiation. The danger is, in the first instance, the local perturbation in our heat-economy, which has partly local consequences, but also and chiefly disorders the nerves, acting on the calibre of our blood-vessels, our vaso-motor nerves, which have to regulate the outflow of our heat. When we are in the open, and the air is in more motion than the air of a draught, we speak of wind, etc., etc., but seldom of draught, because the whole air-current flows equally all round us, just as in a well-ventilated room, only with greater velocity.

The vaso-motor nerves, regulating the circulation in our skin, are beyond our control, and we cannot bid them to defend us simply at the place attacked by the draught. They know only how to serve our heat-economy when the outflow of heat from our bodies is equal, or nearly so, on all sides. They misunderstand the local irritation for one spread over the whole surface, and act at once on this error. If one perspires and goes to the window with bared neck or chest, one feels a shiver not only there but all over the body, and the perspiration becomes suppressed accordingly. The blood which at the time filled the blood-vessels of the glowing skin is displaced by the contraction of its channels; but by the misunderstanding of the vaso-motor nerves it is driven not only from the exposed parts but from the whole sur-

face towards the internal parts. If one or some of them are in some state of weakness, danger or bad consequences cannot fail. It is the same thing as with a large quantity of cold water taken in too quickly when the body is heated. A draught, then, is injurious only in so far as it causes perturbations in our heat-economy, and as these perturbations can be caused in different ways, we often accuse the draught wrongly.

We hear often, "I don't like sitting near this window, close to this wall," and so on, "there is always a slight draught coming from there." We fancy that we feel the draught, the motion of a wind, but it is mostly increase of one-sided heat loss by radiation towards the cold place. People generally believe rather, that the wind comes through the wall. But the velocity of such a wind is too small to be felt as air in *motion*, and a piece of carpet fixed to the suspected wall does away with the supposed draught. It could, therefore, not be caused by the air-rush through the wall, because the carpet is many times more permeable to air than the wall.

I hope in future, ventilation and draught will be to your mind two distinct things.

THIRD LECTURE.

ON THE RELATIONS OF THE AIR TO THE SOIL, OR ON THE GROUND-AIR.

If in the two preceding lectures I have tried to draw your attention to the penetration of the air into our clothing and our dwellings, I shall try in this last lecture to do the same in reference to the air which is in the ground, and to its connection and intercourse with the air above the ground. The air in the ground has been somewhat a stranger to our minds; the terms air and earth, just like air and water, implied to our mind things contrary, and exclusive of each other. The earth seemed to have its limit where the air began. Common sense seems inclined to believe that there can be no air in that whereon we walk and stand. If we say of the surface of the earth, that it is the limit of the earth and the beginning of the atmosphere, we are not correct in reference to the latter. The air begins much below the ground, and we ought to say that where the ground, which is a mixture of earth, water and air, ends, from there the atmosphere exists alone. It is no wonder that no particular attention was paid to the air in the soil; its presence there does not make any direct impression on any one of our senses; we infer its presence more from other experiences and consequent conclusions. The human mind formerly looked

upon the air as something unsubstantial, spiritual, although men saw the effect of hurricanes; no wonder, then, that no one thought of the air hidden in the ground, which cannot even blow the hat from our head.

We again meet here with the fact that, originally, only that calls forth ideas, which impresses our senses directly. No one doubts that water penetrates the soil, and moves there according to hydrostatic laws, because we see it run, vanish into the soil, collect and run out again, or we pump it up, but hitherto not many have clearly understood that the whole surface of the earth, as far as it is porous and its pores are not filled with water, contains air, which is also subject to aerostatic laws. And why so? One feels nothing of that air, it is always calm, it has no colour, no smell, no taste, in fact we take it for nothing. I have shown you already how great an error we commit when we suppose a calm air to be motionless. This applies just as much to the air in the soil, which, if its motion were even snail-like, would still travel from a good depth to the surface in one day.

Perhaps I shall succeed in giving you a better idea of the change of the air in the ground than of that in walls. To have a correct idea of that air and its relations, we must know, in the first instance, its quantity in proportion to the different kinds of soil. Let us first take rubble soil, gravel, or sand, which support the largest and heaviest edifices. Here is a bottle which holds exactly one litre ($1\frac{1}{10}$ pint) up to that mark on its neck. I have filled it slowly with gravel, shaking it all the while, so that the gravel settled completely. The gravel reaches up to the mark. This high cylinder contains just one litre of water, and is graduated into one hundred parts. Now I pour the water into the gravel, till I find it just

coming up to its surface, and I see that of the water in the cylinder thirty-five parts have entered the gravel and driven out the air, which before had therefore taken up 35 per cent. of the whole mass. This is certainly a great quantity of air, and if we build a house on such a ground its weight rests no doubt on the gravel alone, and not on the air; but for all that, this ground, as far as it is dry, consists to the extent of one-third of air. In building on gravel, we build as well on air, just as we build on water when we build on piles driven into a swampy soil and cut off under the water. We know well that a house standing on piles, stands with its foot in water, that this water is drawn up by the walls till beyond the water-mark, that the water of the ground has a good deal to do with the house; why should we then refuse to acknowledge that the foot of a house built on dry gravel, stands also on the air, and that the air in the ground is in intimate relation with the house?

What I have shown you in regard to gravel, can, in a similar way, be proved in regard to sand, clay, and even more solid stony and rocky soils.

Most kinds of sandstone are nearly as porous as loose sand. The rock of Malta has been proved by Leath Adams to suck up water on an average to one-third of its volume; consequently when dry it must contain air to the same extent. One would not think that this was the case with the rugged cliffs and shores of that remarkable island, which look as if they were built up from the granite of the Swiss Alps. Most buildings in Malta are built with this Maltese rock, which is much used also throughout Italy. It is not less porous than the Berlin sands; their penetrability for air and water are the same, but the grains of the Maltese rock are connected by some solid medium, while the grains of the sand are loose. In

respect to their porosity they stand relatively as frozen and not frozen soil.

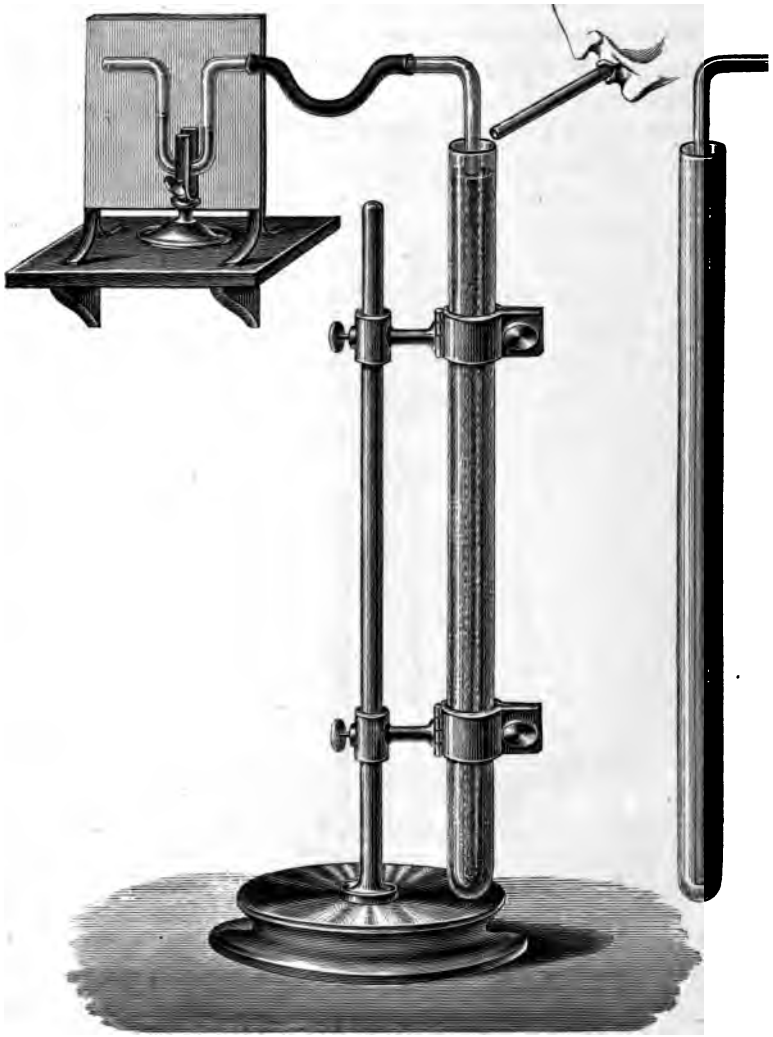
Many ships of the English navy have filters made of a certain kind of Maltese rock. I have tested one, and I have found that the filtering basin swallows up 47 per cent. of its whole contents, when used for the first time.

A soil whose pores are filled partly by air and partly by water, is called damp. It can take up more water till all its pores are filled with it, when all passage of air is stopped, just as we have seen with regard to the mortar of the house. That degree of humidity of the soil is called *ground-water;* it begins at the lowest limit of the air in the soil.

It is well-known that water becomes solid at a temperature below freezing point. In becoming ice it changes its consistency totally, but its volume not very much, increasing it by about 6 per cent., one hundred volumes of water becoming one hundred and six of ice. In a frozen soil there must have been a certain quantity of water. This water in freezing has become a kind of cement for the particles of the soil, and gives it a solidity which the liquid water could not impart. Although such frozen soil is as hard to work as stone, we have no right to assume that it is impermeable to air or gases of any kind.

Those pores of the soil which were free from water cannot be narrowed much by the expansion of the neighbouring pores through the freezing of their water. It would be just as incorrect to deny the permeability to air of the frozen soil as that of the Maltese rock. Still the most erroneous views have been formed on this subject, even by men distinguished in other branches of science.

Having given you an idea of the quantity of air in a porous soil, I have to give you a correct idea of the



You cannot longer have any doubt about the motion of the air through gravel; but I want to convince your senses; I want you to *see* the motion of the air, and to *see* that motion taking place through a much thicker stratum of gravel than the strata shutting in the bird.

You see this high glass cylinder, with a smaller glass tube inside, open at both ends. The cylinder is filled with gravel, and the glass tube connected with a manometer by some india-rubber tubing. As soon as I blow gently on the upper surface of the gravel, you see the liquid in the manometer moving. The motion of the air which I produce acts in the first instance on the surface of the gravel, propagates itself through the same to the bottom of the cylinder, enters the lower end of the tube, rises through it and through the tubing into the manometer, where it presses on the column of liquid, and sets it in motion.

Why does the liquid move in the manometer? Because the air, after the migration just described, presses with greater weight on the surface of the column it arrives at than the outer air on the surface of the other column. If there were no liquid in the manometer, the moved air would finally flow out of the manometer, and, as you see, now that I have emptied the manometer, nearly blow out this candle.

In this way I believe that I have convinced your senses that the air can move through porous soils.

If the air in the ground can be set in motion by the pressure of air or wind against its surface, there can be no doubt that the same can be effected by differences of temperature, and by diffusion, and generally by all causes which can produce movement of gases. As long as the air in the ground is of a different temperature or composition from the free atmosphere, there must be exchange

and motion. I will only, in order to leave no doubt on your mind, direct your attention to several well-known facts, which can only be explained by the change of the ground-air.

All Christian nations bury their dead in the earth, to give back to dust what came from dust. There are burial-grounds in which a corpse decays completely in six to seven years, and others in which it takes twenty-five to thirty years. The regulations about a second occupation of a ground depend on this difference, and therefore towns with an equal population may be obliged to have burial-grounds of very different sizes. There are other circumstances of some influence on the process of decay, but the principal one is the amount of, and the facility for the change of the air in the soil. Rubble and sandy soils do the work much quicker than marl and clay soils. Striking experiences in this respect have been made on the French battle-fields, chiefly near Sedan, where a Belgian chemist, Louis Creteur,* had to disinfect the large dead-pits. The bodies were buried in chalk, quarry, rubble, sand, argillite, slate, marl, or clay soils, and the sad work lasted from the beginning of March to the end of June. In rubble the decay had taken place fully, but in clay the bodies were surprisingly well kept, even after a very long time, and even the features could be identified.

As the processes of putrefaction and decay are intimately connected with the activity of certain lower organisms, which prey upon the dead, it is sufficiently clear that these organisms must thrive differently in different kinds of soil. A lively change of air and water in the ground appears to be of great influence in this respect; the more air in the ground the richer the underground life.

* See App.

Remarkable testimony as to the permeability of the ground, and of the foundations of our houses, has been given by Gas emanations into houses which had no Gas laid on. I know cases where persons were poisoned and killed by Gas, which had to travel for twenty feet under the street, and then through the foundations, cellar-vaults, and flooring of the ground-floor rooms. As these kinds of accidents happened only in winter, they have been brought forward as a proof that the frozen soil did not allow the gas to escape straight upwards, but drove it into the house. I have told you already why I take the frozen soil to be not more air-tight than when not frozen. In such cases the penetration of Gas into the houses is facilitated by the current in the ground-air caused by the house. The house, being warmer inside than the external air, acts like a heated chimney on its surroundings, and chiefly on the ground upon which it stands, and the air therein, which we will call the ground-air. The warm air in the chimney is pressed into and up the chimney by the cold air surrounding the same. The chimney cannot act without heat, and the heat is only the means of disturbing the equilibrium of the columns of air inside and outside the chimney. The warm air inside is lighter than the cold air outside, and this being so, the former must float upwards through the chimney, just like oil in water. It continues to do so as long as fresh cold air comes into its neighbourhood from outside. As soon as we interrupt this arrival, the draught into the chimney is at an end. Any other way of looking at the action of chimneys leads to erroneous views, which have many times stopped the progress of the art of heating and ventilating.

Thus our heated houses ventilate themselves not only

through the walls but also through the ground on which the house stands. If there is any Gas or other smelling substance in the surrounding ground-air, they will enter the current of this ventilation.* I have witnessed a case in Munich, where not the least smell of Gas could be detected in the street, but a great quantity of Gas found its way into the ground-floor room of a house where no Gas was laid on. In another case the Gas always penetrated into the best heated room and produced an illness of its inmates, which was taken for typhoid fever.

The movement of Gas through the ground into the house may give us warning that the ground-air is in continual intercourse with our houses, and may become the introducer of many kinds of lodgers. These lodgers may either be found out, or cause injury at once, like Gas; or they may, without betraying their presence in any way, become enemies, or associate themselves with other injurious elements, and increase their activity. The evil resulting therefrom continues till the store of these creatures of the ground-air is consumed. Our senses may remain unaware of noxious things, which we take in, in one shape or another, through air, water, or food.

We took rather a short-sighted view all the while, when we believed that the nuisances of our neighbours could only poison the water in our pumps; they can also poison the ground-air for us, and I see more danger in this, as air is more universally present, and more movable than water. I should feel quite satisfied if, by my lectures, you were convinced of this important fact, if of none other.

England has given proof how the public health can be

* I believe that there is great protection in this respect for *houses in England* by the sytem of areas.—TRANSLATOR.

improved, by keeping the soil clean through good drainage, abolition of cesspools, and abundant water supply. It would carry me too far if I were to analyse now to which of these measures the lion's part belongs; I should have to enter upon many controversies, which I have no time to fight out in this place; but this is my conviction, which I want to impress upon you, that cleanliness of the soil and diminution of organic processes in the ground of dwelling-houses, are most essential.

Many have considered these processes, and their effects on the Ground-air, to be a mere hypothesis. This view lies now behind us, and facts have been found proving their reality. Stimulated by the investigations of Huxley and Hackel, further researches have followed, and shown that not only at the greatest depth of the sea, but also in every porous soil, there are everywhere those beginnings of organic life, belonging neither to the animal nor vegetable kingdom, mucous formations, which are called Moneras and Protistes. When I wrote my part of the report on the cholera in Bavaria, in 1854, I pointed out already, that the air not less than the water in the soil, ought to be drawn into the circle of experimental investigations. Neither others nor myself acted at once upon my suggestion, and it is only during the last eighteen months that I have examined the Ground-air in the Rubble-soil of Munich, regularly twice a week, for its varying amount of carbonic Acid. The results are surprising, and for the future I shall have to trouble others and myself not only with Ground-water, but also with Ground-air.

The place where the examination of the Ground-air of Munich is being carried on is Rubble, without any vegetation, and the carbonic Acid increases with the distance

from the surface. Agricultural chemistry has been aware, for a long time, that a clod of arable earth which is rich in humus, is a source of carbonic Acid, but no one expected that, at times, so much carbonic Acid should be met with in sterile Lime-rubble. A few feet under the surface there is already as much carbonic Acid as in the worst ventilated human dwelling-places.

I have found that the quantity of carbonic Acid is smaller at 58 inches than at 156 inches throughout the year, the months of June and July excepted, when an inverse proportion arises. But then there begins also, in the lower stratum, a considerable increase, so that the upper stratum soon finds itself behind again. This large quantity of carbonic Acid in the Ground-air of Munich has been far surpassed in Dresden. Examinations have taken place in this town under the authority of the Central Board of Public Health. Professor Fleck's diary proves that, at least at that spot where his examinations took place, the quantity of carbonic Acid was in winter already nearly twice as great as in Munich in the month of August. I might become jealous of Dresden, but we must often, in life, put up with being left behind, although we had the first start, and I have no choice left but to resign myself.

The presence of carbonic Acid in the soil and its periodical motion, are for the present a bare fact. Other places, with different soils, must be examined under varying circumstances, and for longer periods, before an explanation can be attempted.

The first question which naturally meets us, is that about the origin of this gas. It cannot spring from the humus of the surface, because at Munich and Dresden its quantity is smallest in the immediate neighbourhood of

the surface, where the humus lies, and increases in proportion to the distance from thence. As the amount of carbonic Acid in the Ground-air generally increases the nearer this is to the Ground-water, we should be at first sight inclined to assume that it evaporates from it. Is it not a fact, that the Ground-water which feeds wells and sources, contains this gas? And is it not well known that many a well's shaft contains so much carbonic Acid as to extinguish a burning candle at the distance of a few feet only from its opening? This assumption, however, is not justified for several reasons, according to the researches and experiments made at Munich. First, there are two months in the year when the amount contained in the upper stratum, which is at the greatest distance from the Ground-water, is larger than in the lower. Secondly, I have examined simultaneously, at given places, the amount of the gas both in the Ground-water and in the Ground-air, and have investigated whether, according to the laws of diffusion and absorption, either had a surplus of the gas, and was accordingly in a condition to receive or yield some of it. In every case the amount of carbonic Acid in the Ground-air was larger by 50 per cent. than in the Ground-water, so it is clear that it is the water which receives its carbonic Acid from the air, and not *vice versâ*.

Hereby the question about the origin of the gas is certainly not yet answered, and would have been left equally unsettled if we had to ask: Whence comes all the carbonic Acid which is found in the Ground-water? All this water is precipitated from the atmosphere, from rain or snow. In entering the soil as meteoric water, its amount of carbonic Acid is exceedingly small. By help of Bunsen's analytical tables, it is easy to calculate, from the quantity

of carbonic Acid in the atmosphere, and the absorbing power of water for this gas, that one pint of rain-water at the average temperature and barometrical pressure, can only contain a very small fraction of a grain of carbonic Acid, and this has been proved further by analytical experience. But the analysis of the pump-water in Munich which was poorest in carbonic Acid, showed that it contained on an average $1\frac{1}{2}$ to $1\frac{9}{10}$ grains of the free gas. The Ground-water at the places of examination stands about 16 feet from the surface. It is therefore evident that the meteoric water, which is the sole source of the Ground-water, must more than centuple its original amount of carbonic Acid before it reaches the wells. Thus much is certain, that the source of the carbonic Acid must be sought for in the soil, and for this reason the more natural supposition is, that the soil yields the gas and gives it to the water and to the air simultaneously, but naturally with greater facility and in greater quantity to the air than to the water. The sources of the carbonic Acid in the soil have now to undergo a stricter investigation; the probability is, they owe their origin to organic processes in the soil.

Allow me, now, a few more concluding and valedictory words.

In the Introduction to my Lectures I thought it incumbent upon me to give you my views about popular Lectures in general. Those views necessarily excluded the possibility of disposing, in a few hours, of any one subject of Hygiene in such a manner as to impart to my audience a thorough theoretical and practical knowledge. My hesitation in selection lasted some time. I might have collected and described the last works and tendencies in the field of Hygiene, pointing out what had practically

succeeded, and what ought to be aimed at further—and there is a series of interesting points and facts, forming a most grateful subject for lecturing; or I might have attempted to give you a survey, a kind of bird's-eye view of the whole domain of hygienic science. There is a charm, in the contemplation of a grand and beautiful distant landscape, in marking, first, the more interesting points, then to let the eye wander round them till it comes to the next striking point, and to enjoy to the utmost the sight of the rich view.

I might, perhaps, have succeeded in satisfying your expectations up to a certain point, but I thought it preferable to direct and to concentrate your attention mainly upon one single object which is known to everyone, and which seems to be so thoroughly examined that many believe that there is very little to say about it—the air, in its hygienic relations to man's clothing, to his dwelling-place, and to the soil on which he builds.

It is such a natural error to imagine that we cannot but understand everything with which we are in continual intercourse; but if we take the trouble of looking a little more closely into everything of which we make daily use, we shall soon make the humiliating discovery that we are acting pre-eminently according to instinct and tradition, and much less by personal understanding. Each period has its own task, to contribute and to create something by which civilisation gains materially or ideally. But if at any one period we examine into the daily life of its generation, we shall find a great deal more that is inherited than self-acquired. This fact ought to make us modest and zealous, but also just and thankful towards our forefathers, who did not possess or know many things which we possess and know now.

As animals make use of Nature and her laws in a multifarious and surprisingly appropriate manner, so does man also. Each carrier on the road makes use of the laws of motion and friction, and of those of living force and its preservation, but he does so for the most part quite mechanically, so that he appears to think no more about it than the beaver when he builds his hut. Man also does most things long before he understands them, and this is part of his nature. If he could make use of things only after having thoroughly investigated them, his life would be a poor one, and barely possible. If we had to study the functions of our clothing and its material before we could put it on, we should be frozen to death long before, and no carrier would have attempted to horse his cart before the time of Galileo and Newton.

Here I find myself drawing a dangerous parallel. You may ask me at once, whether I believe a carrier will be a better carrier for understanding the laws of motion, and whether our clothing and our dwellings will one day be superior to what they are now, because we shall then have learnt to understand their functions better. I leave the answer to the future with the utmost confidence. The experience of the past sets me completely at ease. At all times and everywhere it has been the case, that each progress in the recognition of laws, that each new fact established, and each new method applied by science, each new way on which science has directed us, have finally had their practical and useful consequences. Excuse me if I continue to dwell on this favourite subject of mine.

What men call useful is quite a relative term; they call *a thing so as soon* as they find out what use they can

make of it. Of course a thing must exist before we recognise it, and we must become aware of certain of its properties and relations before we can make use of them for any practical purpose. Certainly the recognition of the laws of motion by Galileo, Kepler, Newton, Laplace, and others, have not brought about a revolution, or made a sensation among the carriers, but from these recognised laws sprang and were evolved new ideas, purified from the gross primitive slag, and they led on to the railway, &c., &c. Other examples demonstrate still more clearly the connexion between theory and practice.

Electric telegraphy, which is not only practical and useful, but already indispensable to us, had its first origin in the observations of the anatomist Galvani, who saw the legs of frogs quiver when they came in contact with different metals. Imagine to yourself great practical men of the time, whether statesmen, or divines, or soldiers, or physicians, witnessing Galvani's experiments going on year after year; certainly every one of them would have thought that the man could apply himself to something more useful. But from that form of electricity, which Galvani detected, there sprung the researches and works of Volta, Sœmmering, Steinheil, Morse, and Wheatstone, to whom we owe the whole of our telegraphic system. Place together in your mind the quivering leg of the frog and the transatlantic cable.

After the discovery of Columbus, the Spaniards found in the sand of a river grains of a white metal, which was not affected by fire, and appeared therefore to be a noble metal. Quantities were brought to Europe, and the new metal received the modest name of Platina (low silver), this being a diminutive of La Plata (silver). The Masters of the Mint, the gold and silversmiths, had soon formed

their ideas about the new metal; it could neither be melted by itself, nor hammered, nor rolled, nor dissolved in aqua fortis. It was only soluble in aqua regia and other melted metals, but the combinations were all brittle and discoloured; in short, it came to be considered a perfectly useless metal, practically worth less than lead and iron. Its importation was prohibited by the Spanish Government, because there was the danger of its high specific gravity leading to its use for the adulteration of gold. What Platina there was in the country already was thrown into the sea by order. But Science, which makes no difference between the useful and useless, and considers every thing useful which increases our insight into the things that are, has quietly held intercourse with the outcast metal; she learnt how to tame the shrew, and since Wollaston, Platina is considered to be one of the most pliable and useful of metals; just what were originally considered its vices have enhanced its value so much in the course of time that weight for weight the "low silver" is paid seven times as much for as the "high silver."

Modern times have not ceased furnishing numerous examples of the same kind, showing that it is not the business of Science to ask for the immediate profit, for the immediate practical use. They do not fail to come forth in time.

Science may point to the words of the Bible: "But seek ye first the kingdom of God and his righteousness, and all these things shall be added unto you." All sciences are provinces of God's infinite kingdom, and in them, as everywhere in God's kingdom, Justice is dealt by Truth alone. This was my stand-point, which helped me over *the doubts* I might have had concerning the *utility* of

these lectures. It seemed to me that the principal thing was not to present to you a series of practical applications and contrivances, but a series of truths, which carry in themselves their use and applicability and impose their authority in proportion as they are talked over more frequently, understood more clearly, and felt more vividly.

But I wanted to tell you the whole truth about the things which formed the subject of my lectures, and it became my duty to draw your attention not only to what is positively known, what is complete, what requires no further investigation, but also to point out to you much greater fields of Hygiene, where scarcely a seed has been sown. Otherwise I should probably have jeopardised the only and immediate practical use which my lectures can have here, and which I believe to be this: that the conviction may spread and take root everywhere, that Hygiene has been neglected until now, practically as well as theoretically, and that this neglect is a dark spot on our civilisation, which has to be removed by this generation. This conviction begins just now to lay hold of ever-widening circles of society, and a certain sympathy is stirring for the interests of public health, much more than formerly. The weather seems suitable for ploughing fields which have remained untouched, and for sowing good seeds where a rank vegetation has been growing.

When a current, a general motion of men's minds, sets in towards some definite goal, then it becomes the duty of all those who are their leaders to choose the proper routes with earnestness and conscientiousness. If a good intention in behalf of some object is wrongly directed, it soon turns against the object itself; all those who allowed them-

selves to become interested therein, turn away just as discouraged as soon as they believe, that their good intention has been wasted to no purpose, and hence those unlimited reactions and rebounds in public opinion. I believe that I am under a moral obligation to speak out in this place. I do it here, perhaps, more confidently than anywhere else, because I feel that here I am understood. I feel it, through the very fact that I have been requested to give my lectures before this audience. The request came to me from the Committee of the *Albert Society*, from its exalted *Lady President*. The existence of the *Albert Society*, its organisation, its functions, its efficiency and its authority, are ample proofs that the value of Hygiene is understood here.

In this place I must also acknowledge that the Saxon government was the first in Germany to establish a Central Board of Public Health; it has also included the teaching of Hygiene in the teaching of military medical science. Such arrangements appear to me to be types of the two directions which must now be taken and followed out; on the one hand, investigation, observation, and experiment; on the other, systematic personal teaching. These are the only two ways which lead to the goal.

You have been enabled to see from that single subject I have treated, how much remains to be done and created; every thing is still insufficient and incomplete, and has to be developed and determined. Think of the great chapters—air, clothing, dwelling, ventilation, heating, lighting, building-places and soil—their relation to air and water, and their influence on the course of disease; epidemics, and protection against them; drinking-water, and its distribution among the population; alimentations *and articles of food*; the maintaining of different classes

of men under different circumstances; dietaries; public baths; gymnastics; collection and removal of excrementitious matters and refuse from households and trades; drainage; disinfection; inspection of dead bodies and their interment; unhealthy trades and manufactories, schools, barracks, asylums, hospitals and nursing, prisons, health statistics, &c., &c.

There is not one among these departments of Hygiene in which nothing is left to be done; in most of them the work has scarcely begun. There has always been a desire for, and an aiming at health; but ideas about it have changed completely. The former supports of Hygiene have crumbled away in the powerful analytical solvents of modern physiology, very little has remained, everywhere new foundations are necessary. This requires workmen; the season appears favourable—do not let it pass unemployed.

It is not sufficient to build up correctly a series of hygienic truths, which might be the work of a few; these truths must be brought to bear upon life, and this requires instruments. Three professions are in real life the natural trustees and representatives of the hygienic interests of the community—physicians, architects, and engineers, and also the public administration. There must be harmonious action between them; good intentions are not sufficient, there must be knowledge and power. Only good musicians can make good music, and they must be well taught and practised. The institutions at which the members of these professions have received their education, have all the while generally ignored Hygiene as an independent branch of study. A vague supposition left it to the individuals concerned to take the trouble of gathering for themselves whatever was known or would

be made public about matters of Hygiene. Lectures on forensic medicine, were supposed to be sufficient; but they have to consider facts and evidence only with regard to penal laws, which themselves result from the old and highly-cultivated science of jurisprudence. Hygienic laws must spring from hygienic science, and there was none.

Many of the existing hygienic laws and regulations cannot be kept up if examined by the light of hygienic science as it is now. It is no good going on issuing public regulations demonstrative of good intentions for the public health, the right thing is to create a firm basis for practical purposes and public measures. Hygiene must become an independent branch of study, to be taught by special teachers at universities, medical and polytechnic schools, not without the help of proper laboratories. Systematic instruction must be offered to students and practitioners of medicine, to members of the civil or municipal service, to architects and engineers. Books and reading can as little occupy the place of personal teaching and experimental investigation, as a medical book in the library that of the physician, or a handbook that of the public chair. The self-taught hygienist has frequently to look out for principles on which to act, while he is called upon to act at once, and routine alone is a dangerous and unreliable assistant. There are exceptions, brilliant ones even, but exceptions prove the rule.

The increasing interest taken by the intelligent and well-meaning members of society in matters of public health, which have also an intimate connection with the public purse, cannot fail to assist the whole movement which is taking place in favour of hygienic science and *its independent* and well-endowed instruction.

The whole movement is still going on, but not without resistance here and there. This resistance shields itself sometimes behind the pretext that there are at present not enough well-qualified teachers. Certainly the beginning has its difficulties, but everything must have its beginnings. This was the case with the first periodical in Germany for public Hygiene, founded by Dr. Varrentrapp, which has achieved an entire success in spite of all misgivings and discouraging vaticinations before it was started.* Worthy representatives of the neglected science will be found for teaching it, as soon as a serious demand manifests itself. A certain species of medical men will be quite made for it, after some preparation. Hygiene is, after all, nothing but applied physiology, with particular reference to the physical well-being of mankind. According to my experience, men of science and physicians, who are specially grounded in the practical and theoretical study of physiology, chemistry and natural philosophy, are those who can most easily fit themselves for the special work of hygienic science. It is true, physiology includes the most essential points of Hygiene, and physiology is an application of natural philosophy, chemistry and anatomy. But as the votaries of the latter sciences have never done the work of pure physiologists, so these would never have done, and never will do, the work of pure hygienists. England† has preceded other

* The well-known periodical *The Practitioner*, in its new hygienic department, and the new *Journal of Public Health*, will, no doubt, meet with success.—TRANSLATOR.

† No doubt England, in consequence of her wealth, her unbounded charity, the sad necessities of an unexampled pauperism, the rapid increase of her urban population, and the number and variety of her trades and manufactures, etc., etc., has been for a long time in the van of hygienic improvements of all kinds; but in England, also,

countries in the creation of professorships for Hygiene. I confidently believe that the proper men, in sufficient number, will also be met with in Germany in a short time.

Should my lectures in Dresden have had the effect, in some degree, of turning your hearts and minds towards the most pressing tasks of hygiene, so that every one of you may do his best for them in his own sphere, then I am sure I have done something practically useful, and have not spoken in vain.

much more has to be done—new solutions have to be found for old questions, and a sufficient number of well-qualified hygienists is to be kept up, in order to do effectually the work which devolves upon them in consequence of the Law of last Session.—TRANSLATOR.

ERRATA.

Page 1.—*Read*, creating as they are.

Page 11.—*Read*, 19, *instead of* 9 to 13 inches.

Page 42, 3rd line.—*Read*, although the mortar forms only about ⅛ of the walls.

Page 43, last line but one.—*Read*, or porous colours, or coloured surfaces which are porous.

APPENDIX.

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